WAR DEPARTMENT

TECHNICAL MANUAL

MILLING MACHINES, SHAPERS, AND PLANERS

April 20, 1942

TECHNICAL MANUAL } WAR DEPARTMENT,
No. 1-421 } WASHINGTON, April 20, 1942.

MILLING MACHINES, SHAPERS, AND PLANERS

SECTION I

DESCRIPTION AND MAINTENANCE OF MILLING MACHINES

1. General.—The milling machine removes metal by means of a revolving cutting tool called a milling cutter. With the aid of various attachments, it may be used for boring, broaching, circular milling, dividing, drilling; the cutting of keyways, racks, and gears; and the fluting of taps and reamers.

2. Types of milling machines.—Milling machines may be divided into four general classes, each of which is particularly adapted to certain types of work.

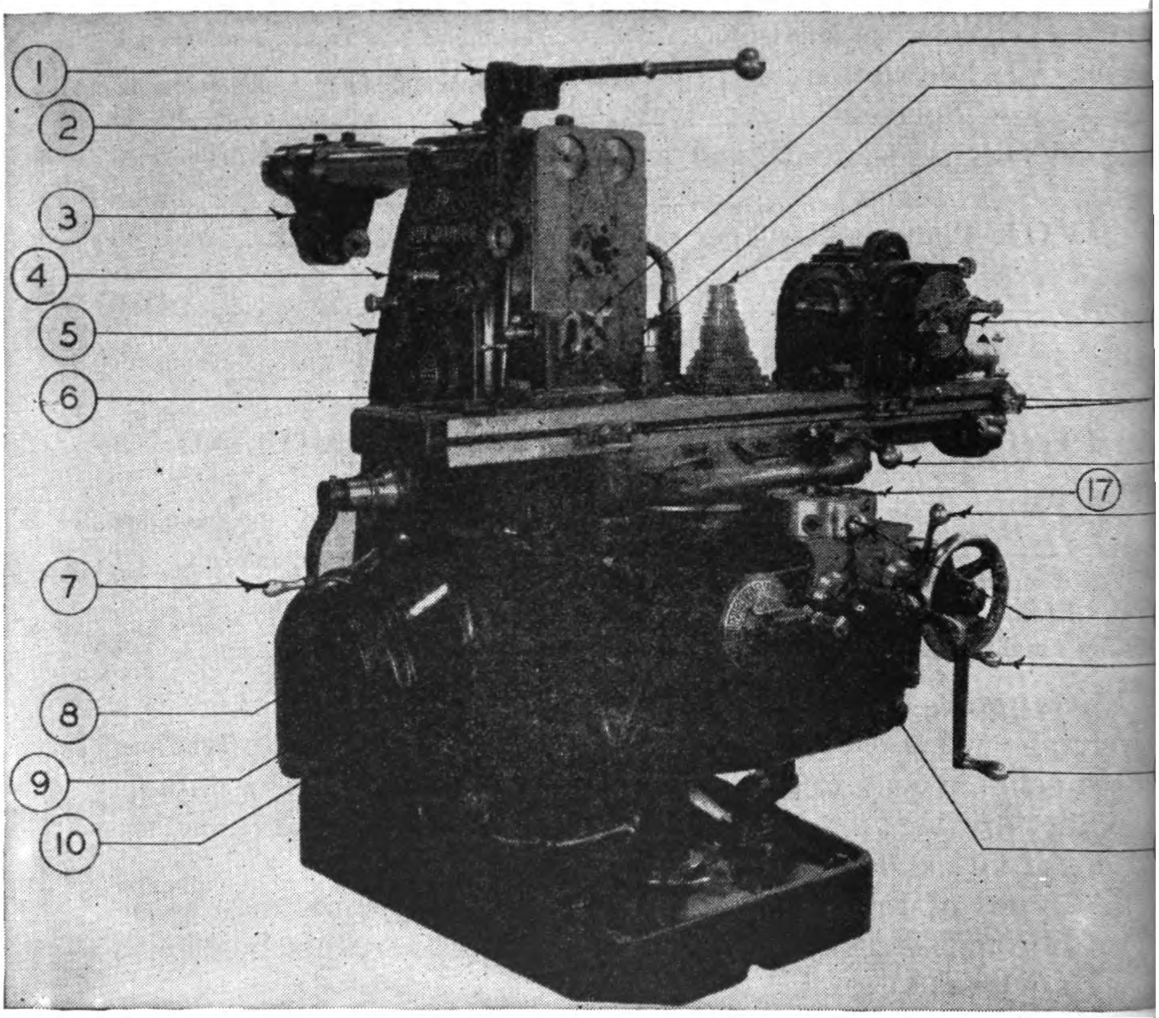
a. Column and knee milling machines.—This class of machine has a saddle on which the work table rests. The saddle is supported on a knee that may be moved vertically or clamped rigidly to the column. The following machines are of a type which would place them in this class:

(1) The universal milling machine (fig. 1) is so arranged that the

*This manual supersedes TM 1-421, July 12, 1941.

adjustment and movement of the knee, saddle, and work table may be accomplished either by hand or power. A distinguishing feature of this machine lies in the fact that it is possible to swivel the work table on the saddle with respect to the spindle axis. With the numerous attachments that are made for the universal milling machine, a great variety of operations may be performed.

(2) Plain milling machine is similar to the universal type in many respects, the principal difference being that it does not have the swivel table.



1. Starting lever.
2. Over-arm clamps.
3. Arbor supports.
4. Speed range change lever.
5. Speed change lever.
6. Speed change selection lever.
7. Table longitudinal crank.
8. Table clamp lever.
9. Saddle clamp lever.
10. Knee to column clamp lever.
11. Footstock.
12. Center rest.
13. Gears for helical milling.
14. Index head.
15. Adjustable table trip dogs.
16. Directional table lever.
17. Universal chuck.
18. Directional cross-feed lever.
19. Directional vertical feed lever.
20. Cross hand wheel.
21. Vertical hand crank.
22. Feed change lever.

FIGURE 1.—Universal milling machine.

(3) Automatic or cycle milling machine is an adaptation of the plain milling machine. The distinguishing characteristic, as compared to the plain milling machine, is the automatic control of the spindle and feed motions by means of adjustable dogs.

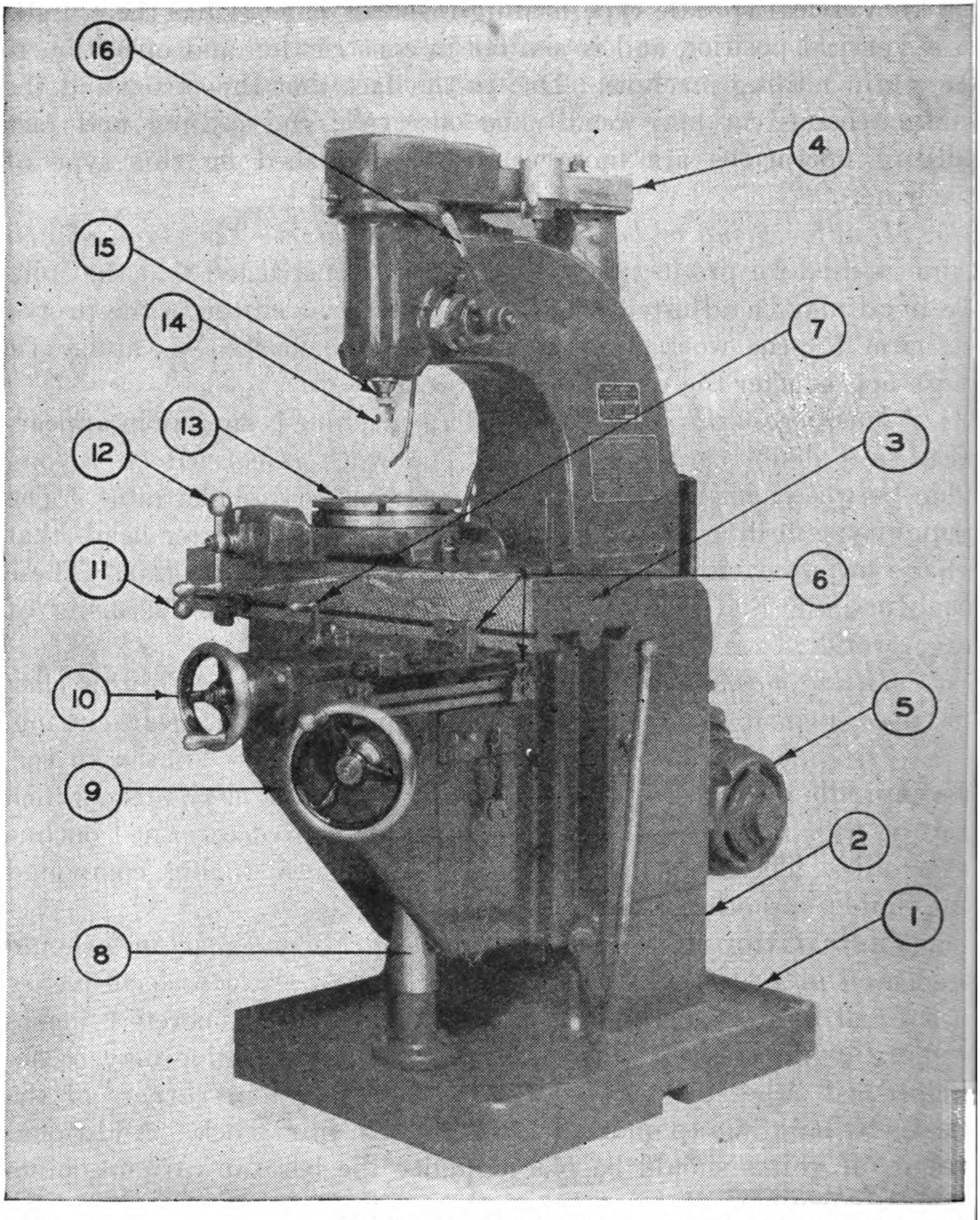
(4) Vertical spindle type milling machine (fig. 2) has the spindle in a vertical position and is similar in construction and operation to the plain milling machine. Due to the fact that the cutter and the surface being cut may readily be observed; end milling and face milling operations are more easily accomplished on this type of machine.

b. Manufacturing or bed type milling machine.—This type of machine is used for production work and is so constructed that the spindle head may be adjusted vertically to bring the cutter to the proper position for the work. In some designs, the machine is automatic in its action after the work has once been set up.

c. Planer type milling machine.—This machine is similar in appearance to a double housing planer. The work is carried on a long table between housings, in the same manner as on a planer table. The planer type milling machine may have one or more cutter heads that can be adjusted either on the cross rail or housing uprights. These machines are used principally in the production manufacturing of large work.

d. Milling machines for special operations.—Machines in this class are used principally for such work as bolt heading, gear cutting, thread milling, and profiling. Profiling machines are similar to vertical spindle milling machines except for the guide mechanism which may be used to cause the cutter to duplicate a predetermined outline or profile. These machines are used in manufacturing compound dies, molds, and other objects in duplicate.

3. Installation and maintenance.—*a.* Milling machines should be located in a position which will allow the operator to have plenty of natural light. The floor or base should be solid concrete 6 inches or more in thickness. Accurate leveling of the machine may be accomplished either by driving wedges under the four corners of the base or by building up under the corners with shim stock. Additional wedges or shims should be placed under the base at various points to evenly support the weight of the machine. After leveling, the machine must be rigidly fastened to the floor by means of lag screws and shields. Another method of securing the lag screws to the floor is to place them in position in drilled holes and pour molten lead around them. To determine whether alinement has been maintained during the fastening down process, the machine should be given a precision level check. Good practice requires additional leveling checks every few months to insure accuracy in the operation of the machine.



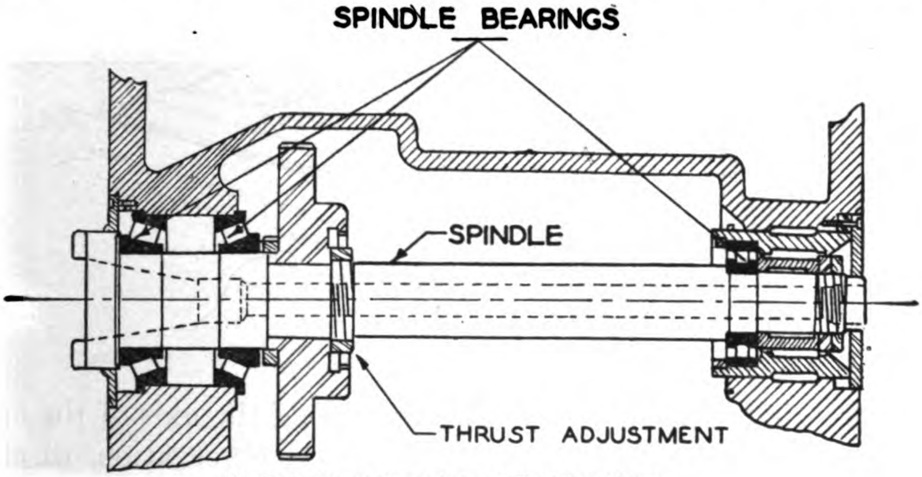
1. Base.
2. Column.
3. Table.
4. Vertical drive pulley.
5. Motor.
6. Stop dogs.
7. Horizontal feed lever.
8. Vertical screw.
9. Vertical feed hand wheel.
10. Cross feed hand wheel.
11. Horizontal feed hand wheel.
12. Circular table feed hand wheel.
13. Circular table.
14. Chuck.
15. Spindle.
16. Spindle hand feed lever.

FIGURE 2.—Vertical spindle milling machine.

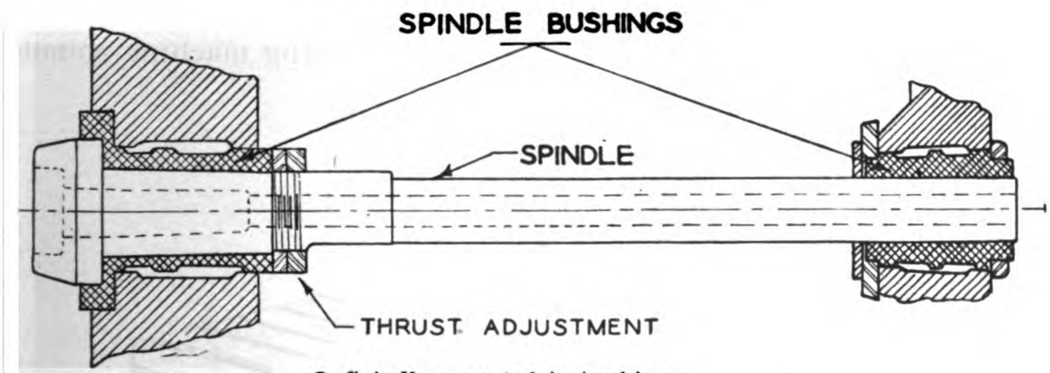
b. Before starting the milling machine, all movable parts must be properly adjusted, oiled, and cleaned. A beginner should start a milling machine at a low speed and carefully observe all moving parts to determine the proper operation of the control handles, stops, feeds, and speed mechanisms before attempting actual operation.

c. Continuously accurate work may be assured by a periodic check on the adjustment and alinement of the machine.

(1) End play of the spindle may be detected by placing a dial indicator against the spindle face and moving the spindle back and forth



① Spindle mounted in roller bearings.



② Spindle mounted in bushings.

FIGURE 3.—Spindle thrust nut adjustment.

along its axis, observing the indicator reading. When play is found, it may be eliminated by tightening the spindle thrust nut as shown in figure 3.

(2) Looseness of the spindle bearings may be observed by chucking a rod in the milling machine spindle chuck and using it as a lever to move the spindle at 90° to its axis. Manufacturers have incorporated various devices such as tapered and split shell bearings, which allow adjustment of bearing looseness.

(3) Accuracy of the spindle may be checked as shown in figure 4. This check is accomplished by placing a test bar in the tapered spindle hole and clamping an indicator on the milling machine table with the indicator contact point touching the test bar. The spindle may

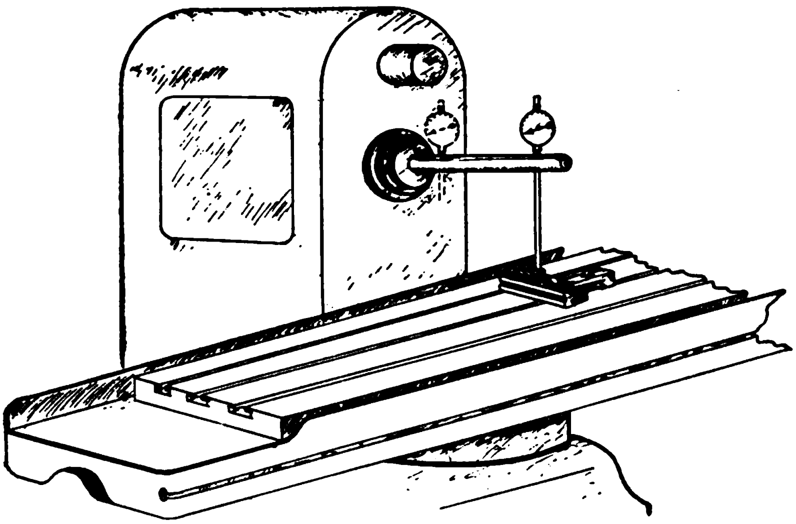


FIGURE 4.—Method of checking accuracy of spindle rotation.

then be rotated while the table is moved along the axis of the spindle and any inaccuracy observed. Should the observation disclose a deviation from concentricity, the spindle hole must be reamed.

(4) Accuracy and alinement of the table, knee, and column surfaces may be checked by placing a test bar in the milling machine spindle

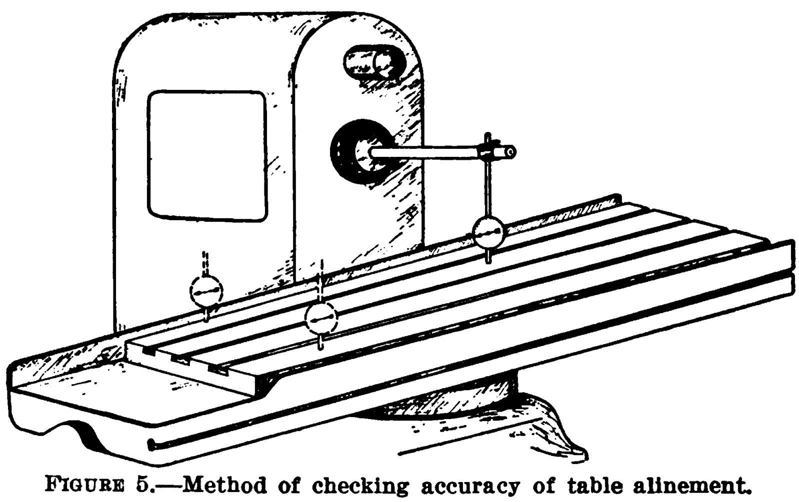
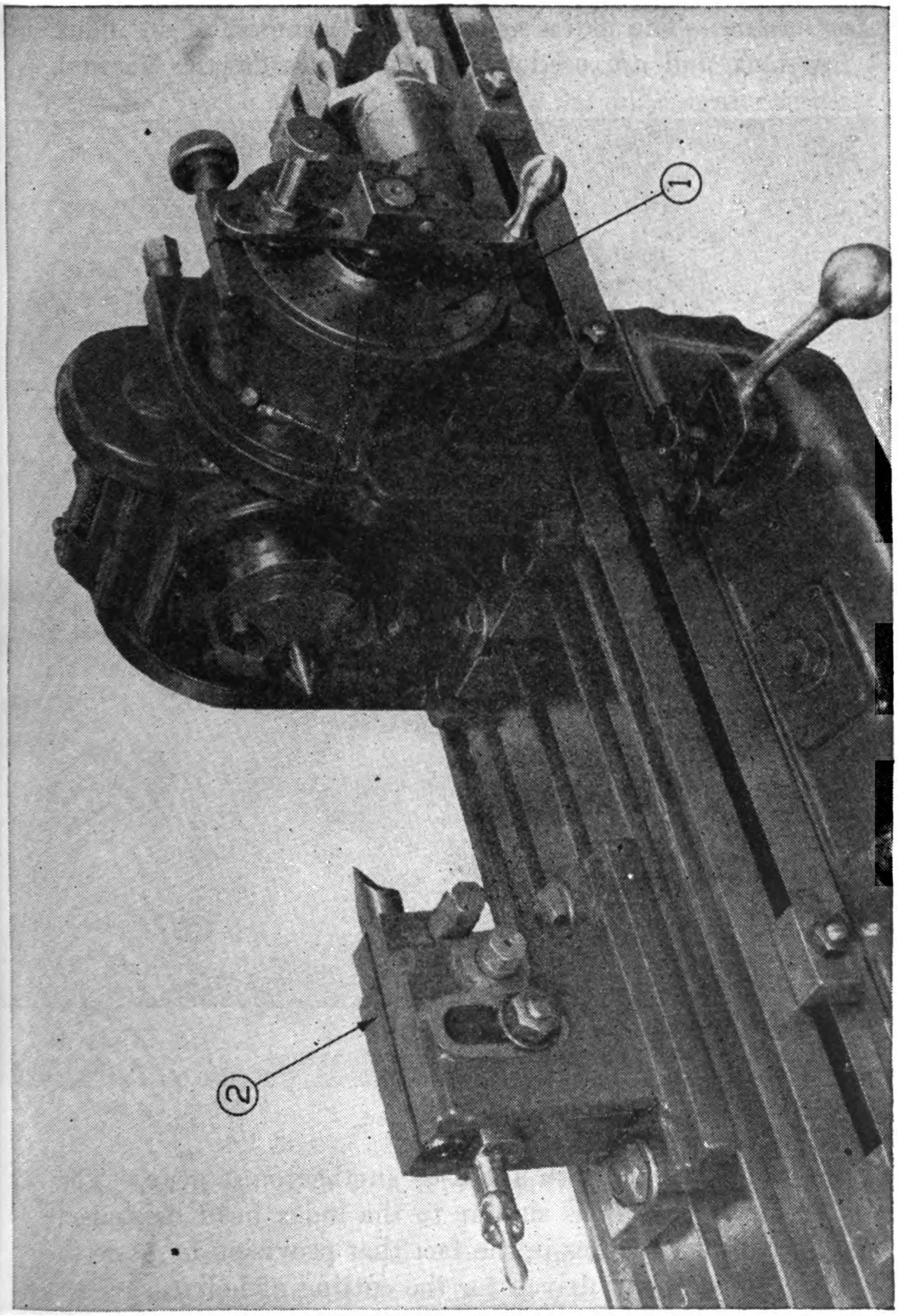


FIGURE 5.—Method of checking accuracy of table alinement.

and attaching the dial indicator as shown in figure 5. With the indicator contact point touching it, the table may then be moved both parallel, and at 90° to the axis of the spindle, so that any variation will be shown on the indicator dial. This test should be carried out with the table set at various heights to determine any deviation from vertical in the column. If the test indicates improper alinement, the trouble may be corrected by adjusting the gibs of the

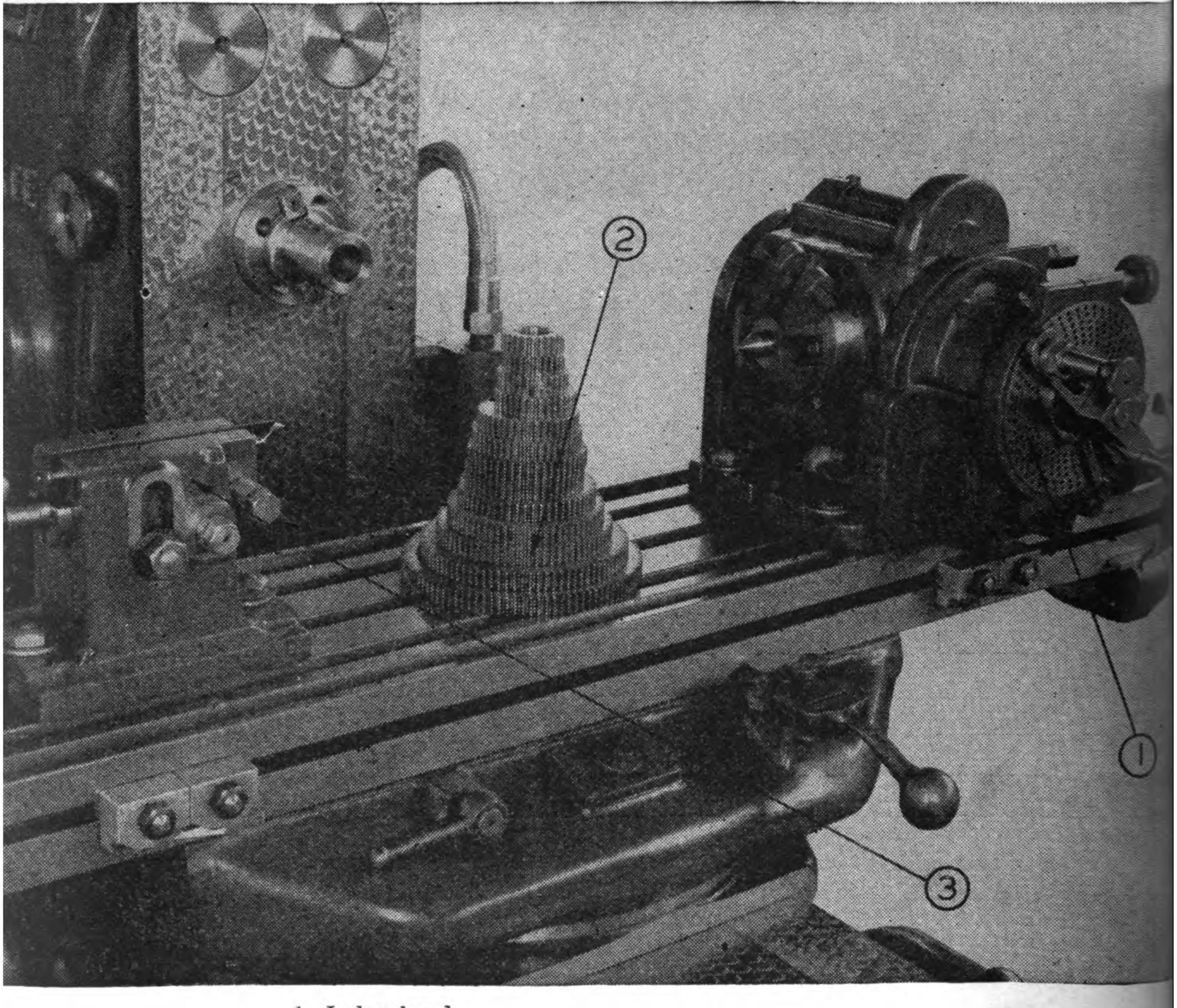


1. Index head. 2. Footstock.
FIGURE 6.—Index centers.

machine, rescraping the bearing surfaces of the table knee or column, or refinishing the work table top.

4. Milling machine accessories and attachments.—*a.* The following items are known as accessories or standard equipment and are usually furnished with the milling machine.

(1) *Index centers.*—The index centers (fig. 6) consist of an index head and footstock and are used to move work a definite amount



1. Index head.
2. Gear selection for driving index head spindle.
3. Footstock.

FIGURE 7.—Universal index head.

about its axis, as from one tooth space to another on a gear. The universal index head (fig. 7) is similar to the index head described above. The chief difference lies in the fact that provision is made to allow its spindle to be power driven for the cutting of helixes.

(2) *Vise.*—Either a plain or swivel type vise is furnished with each milling machine. The plain vise (fig. 8) is used for milling straight work and is bolted to the milling machine table at right

angles or parallel to the machine arbor. The swivel vise (fig. 9) is graduated in degrees around its base, which makes it convenient for milling work at any angle on a horizontal plane. The universal vise (fig. 10) which may be obtained as extra equipment, is designed so that it can be set at both horizontal and vertical angles. This type of vise may be used for all classes of flat and angular milling.

(3) *Center rest.*—The center rest (fig. 1) is similar to a screw

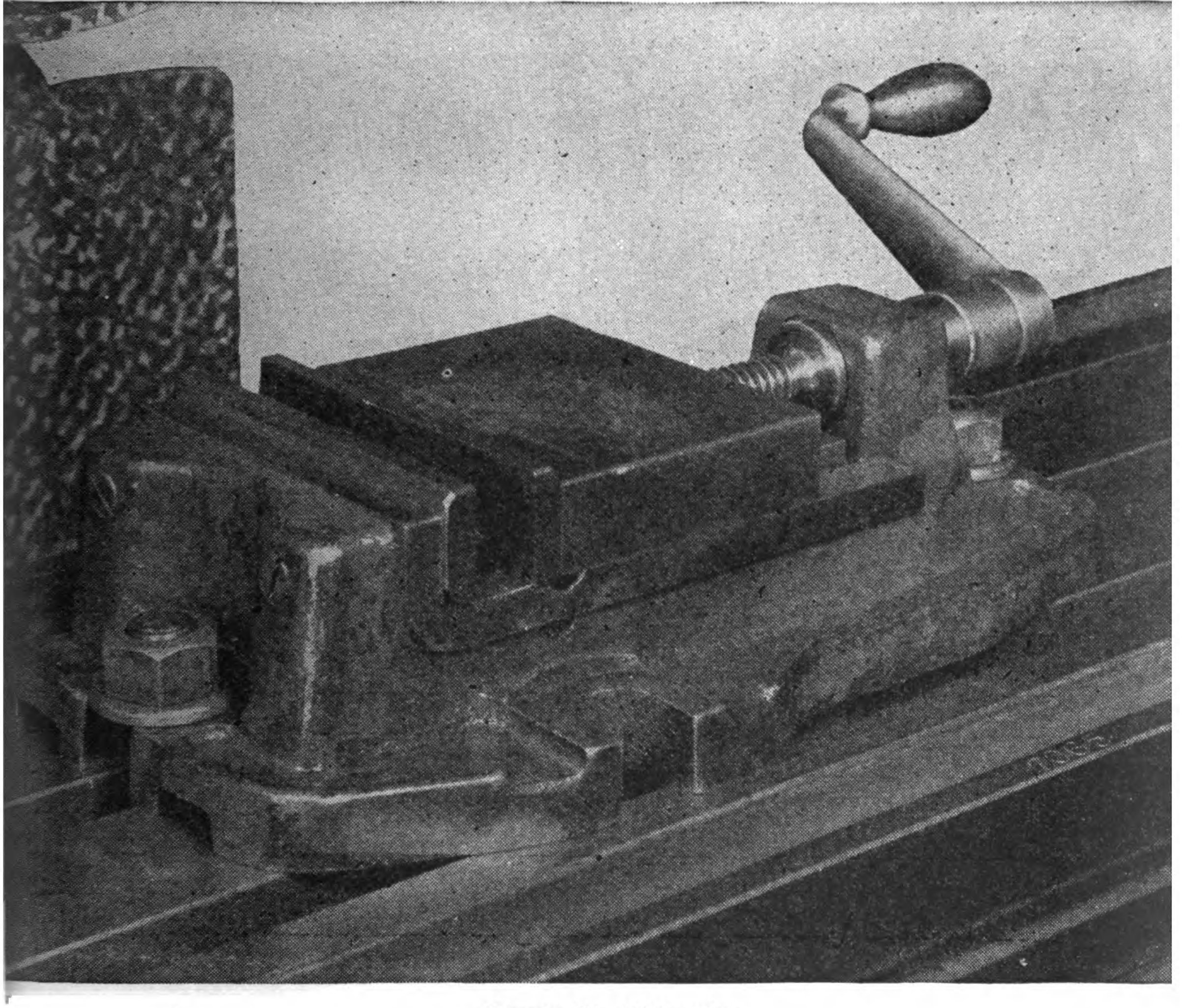


FIGURE 8.—Plain vise.

jack and is used to support work that might spring away from the cutter.

(4) *Coolant drip can.*—The coolant drip can is used to lubricate the work and the cutter. The can and drip tubes have flexible joints so that the lubricant may be directed to the required point. A typical installation of this device is shown in figure 71.

(5) *Wrenches.*—These are ordinarily of the open end or socket

type and are used on the various size bolts and nuts of the machine. Each wrench is designed for a specific purpose and no other wrench should be used as a substitute.

b. Attachments, unlike accessories, are not furnished with milling machines unless specifically ordered. However, at additional cost, manufacturers can supply almost any type of attachment desired for

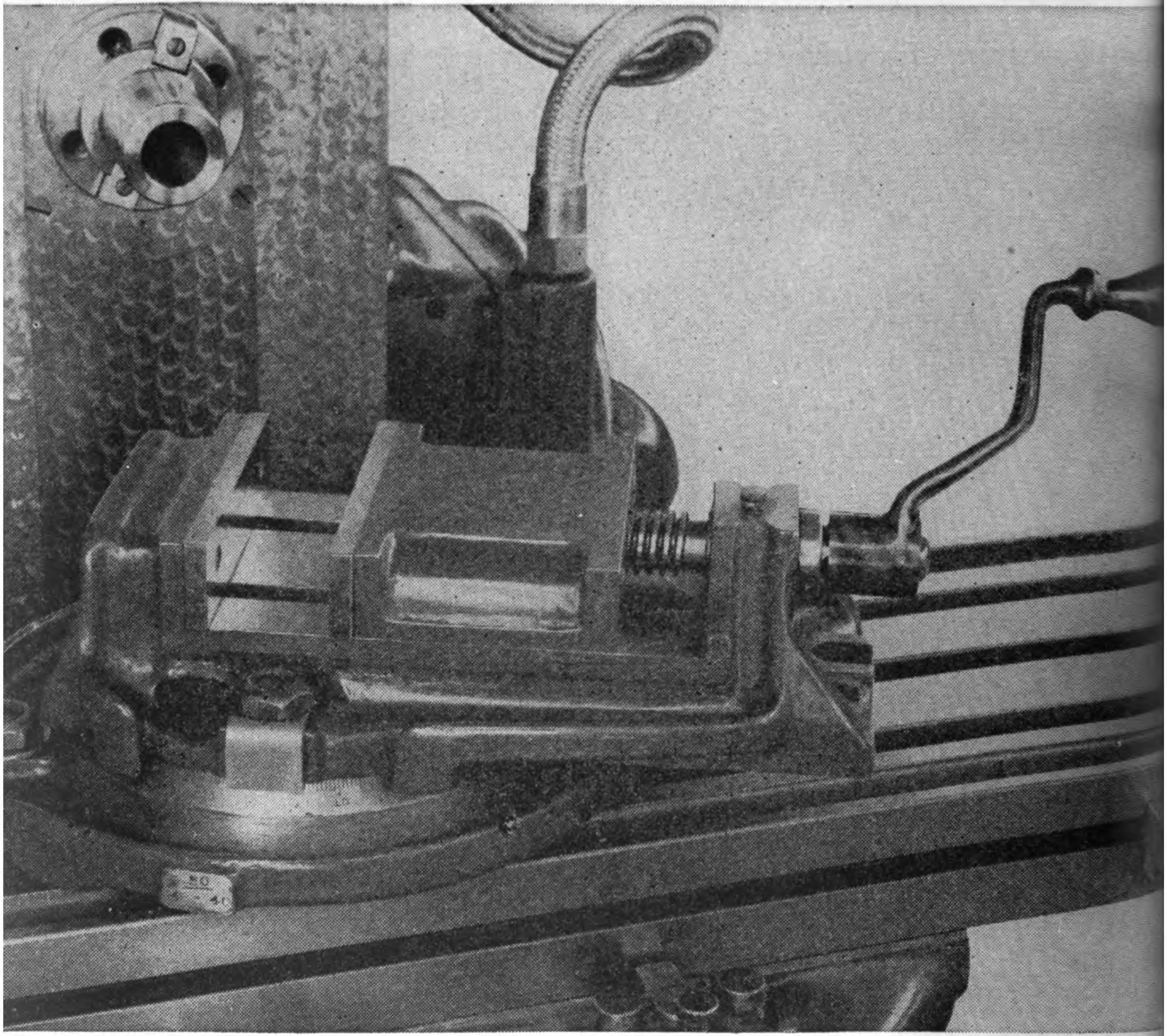


FIGURE 9.—Swivel vise.

use with their machines. The more common attachments are listed below:

(1) *High speed milling attachment* (fig. 11).—The rate of spindle speed of the milling machine may be increased from 1½ to 6 times by the use of the high speed milling attachment. This attachment is essential when using cutters, mills, and drills which must be driven at a high rate of speed in order to obtain an efficient surface foot

speed. It is clamped to the column of the machine and is driven by a set of gears from the milling machine spindle.

(2) *Universal milling attachment* (fig. 12).—This device is one of the most useful attachments of the universal milling machine. Its head can be set at any angle, making it possible to mill a helix of any angle on a horizontal or vertical plane. It can also be used for milling racks, gears, and similar work. When installed, it is clamped to the column and supported by the arm.

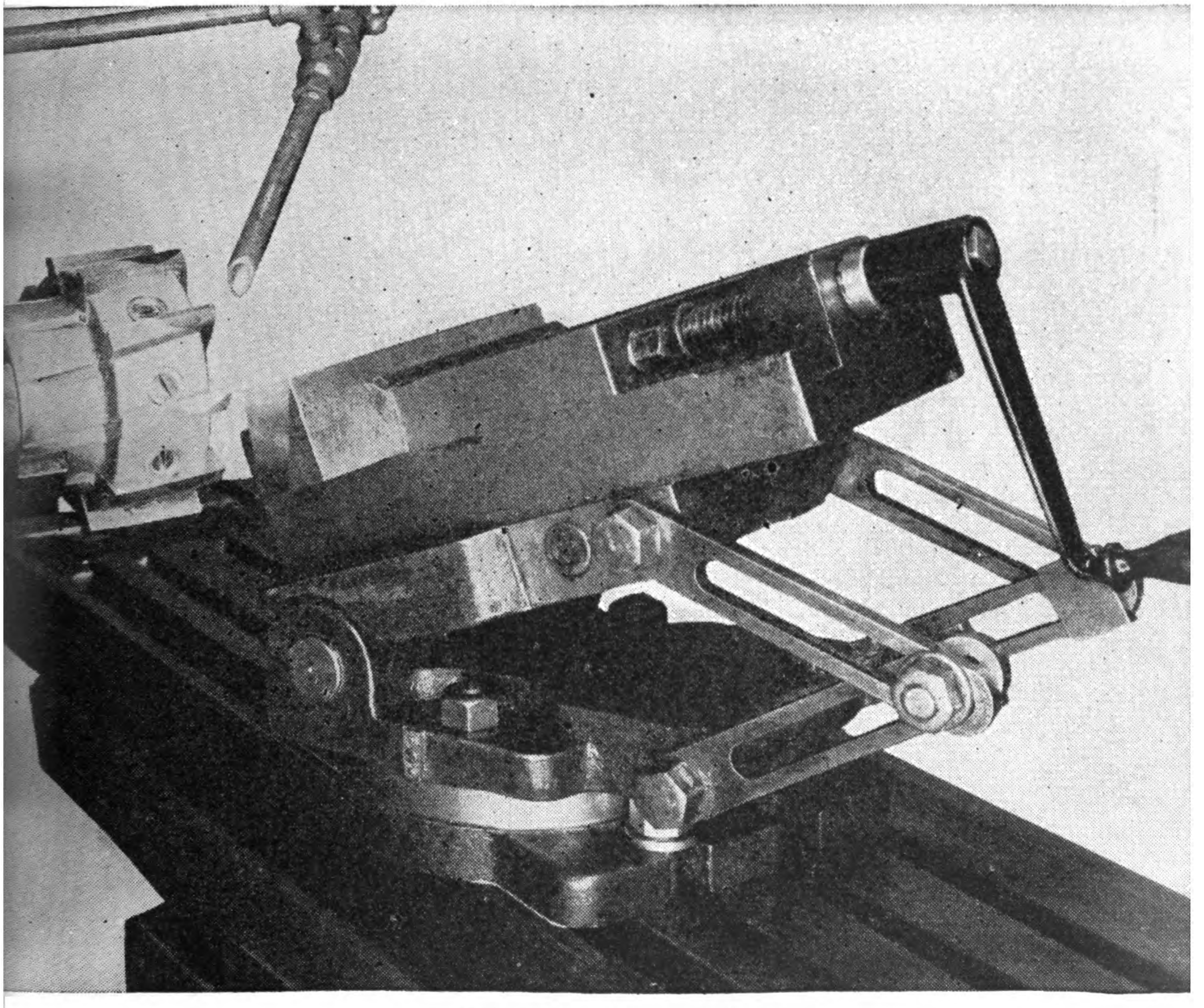


FIGURE 10.—Universal vise.

(3) *Vertical spindle attachment* (fig. 13).—This attachment converts the horizontal spindle to a vertical spindle. It is clamped to the column and driven from the horizontal spindle. It incorporates provisions for setting the head at any angle, from the vertical to the horizontal, in a plane at right angles to the machine spindle. End milling and face milling operations are more easily accomplished

with this attachment, due to the fact that the cutter and the surface being cut are in plain view.

(4) *Circular milling attachment.*—This attachment, as shown in figure 12, may be either hand or power driven. It is bolted to the milling machine table and, if power driven, is connected to the table drive shaft. It may be used for milling circles, arcs, segments, and circular slots, as well as for slotting internal and external gears. The table of the attachment is divided into degrees.

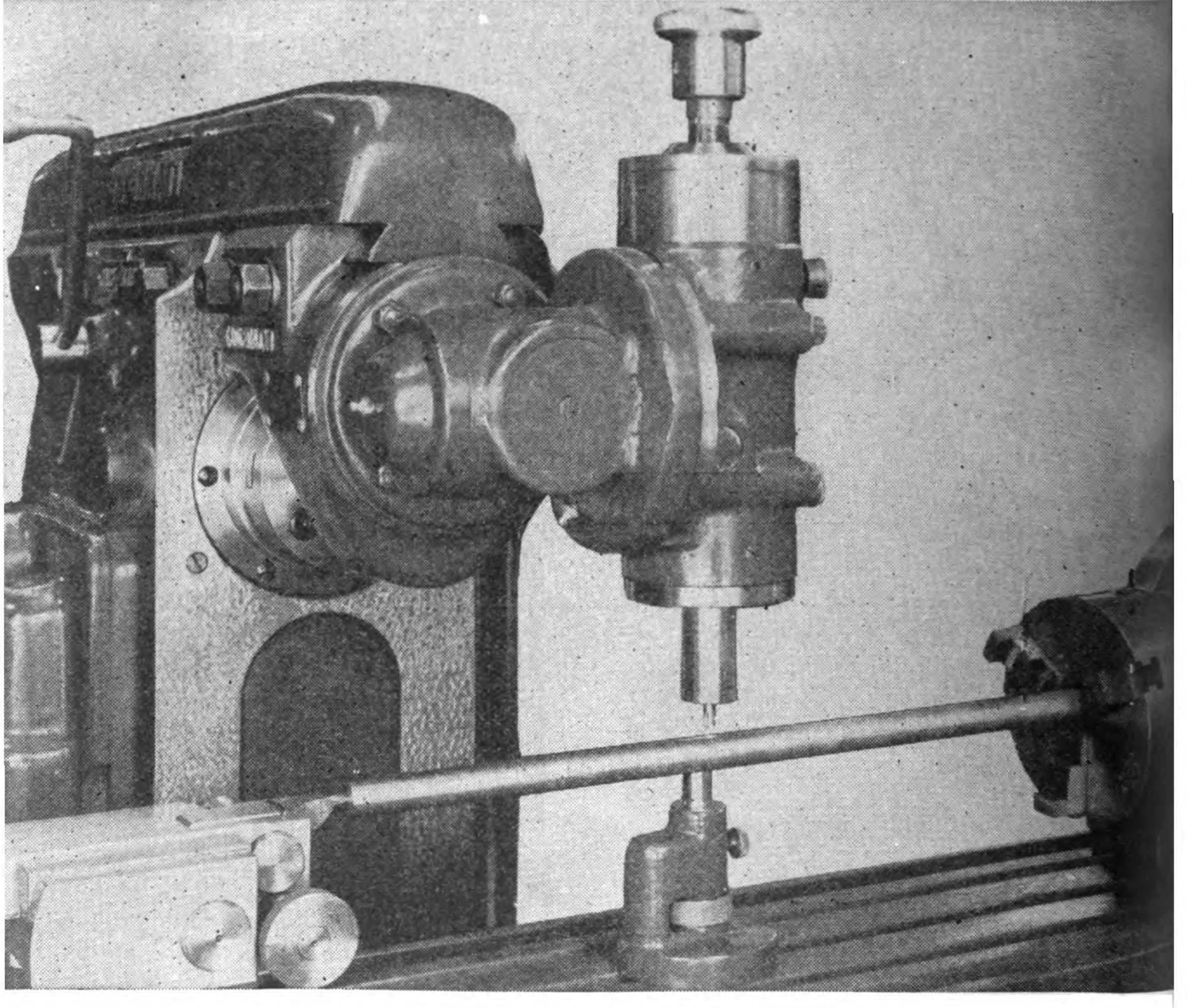
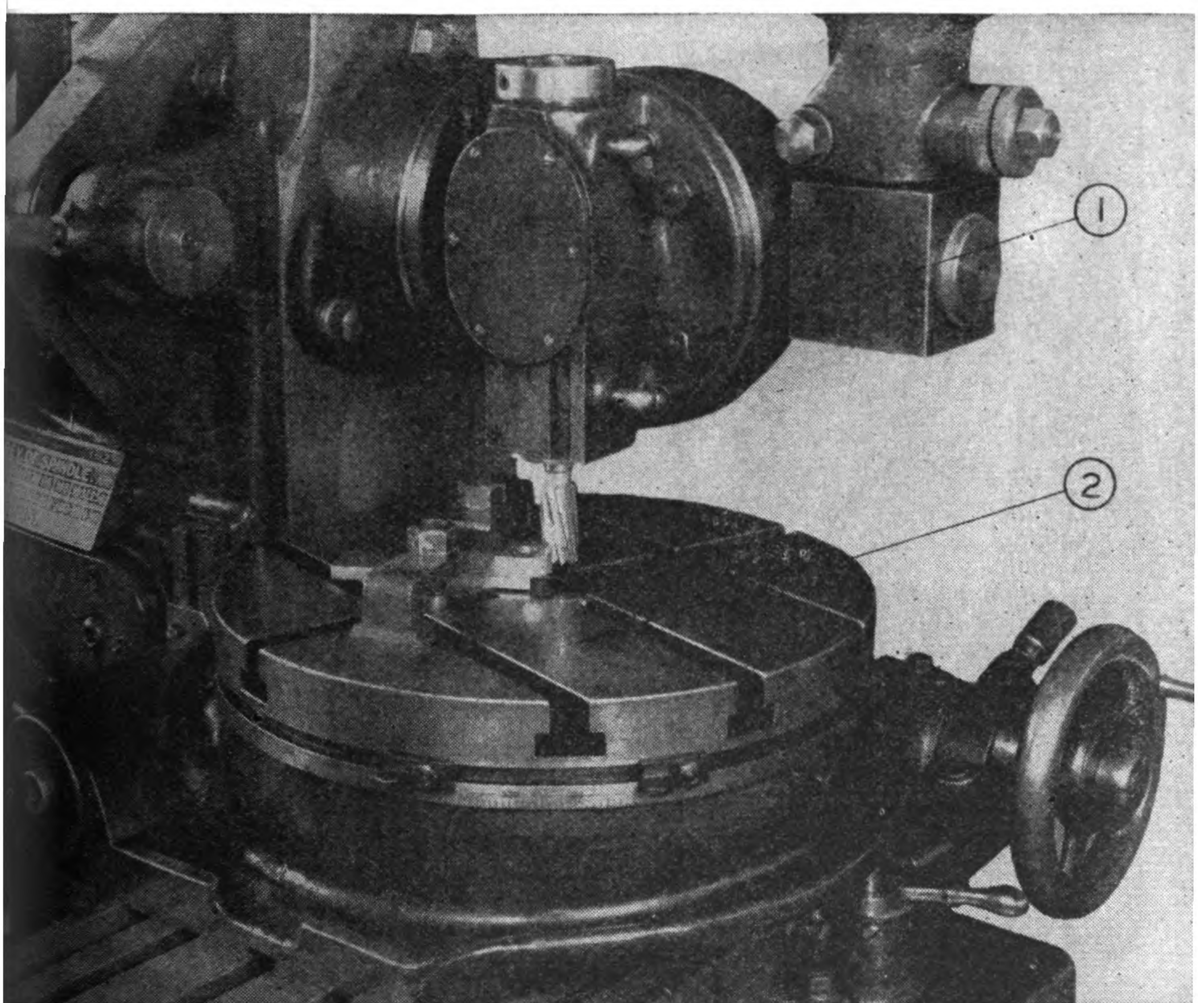


FIGURE 11.—Milling a keyseat using the universal high speed milling attachment.

(5) *Cam milling attachment.*—This attachment is used for cutting drum, face, cylindrical, or peripheral cams, and employs a master cam as a guide in producing the required profile. During the operation, the milling machine table remains fixed and the longitudinal and rotary movements of the work are executed within the attachment.

(6) *Slotting attachment* (fig. 14).—This attachment may be used in place of a slotting or key seating machine. It changes the mill from a machine with a revolving cutter to one in which the tool has a reciprocating motion. The slotting attachment is securely clamped to the column and driven from the milling machine spindle. This device incorporates provisions for setting the head at various angles and the stroke to different lengths. Internal keyways, splines, and



1. Universal milling attachment.
2. Circular milling attachment.

FIGURE 12.—Typical set-up involving the use of a universal and circular milling attachment.

gears can be cut with this attachment and typical operations involving its use are shown in figures 81 and 97.

(7) *Rack milling attachment* (fig. 15).—The spindle of the rack milling attachment is located on a horizontal plane at 90° to the milling machine axis, making the machine convenient for cutting racks to any desired length.

(8) *Offset boring head* (fig. 16).—This attachment may be screwed onto the spindle or inserted into the spindle taper. It is designed to allow the tool to be set off center, making it convenient for many boring operations.

(9) *Raising block or right angle plate* (fig. 17).—The raising block is used when it is required to locate the axis of the index head parallel to the milling machine spindle.

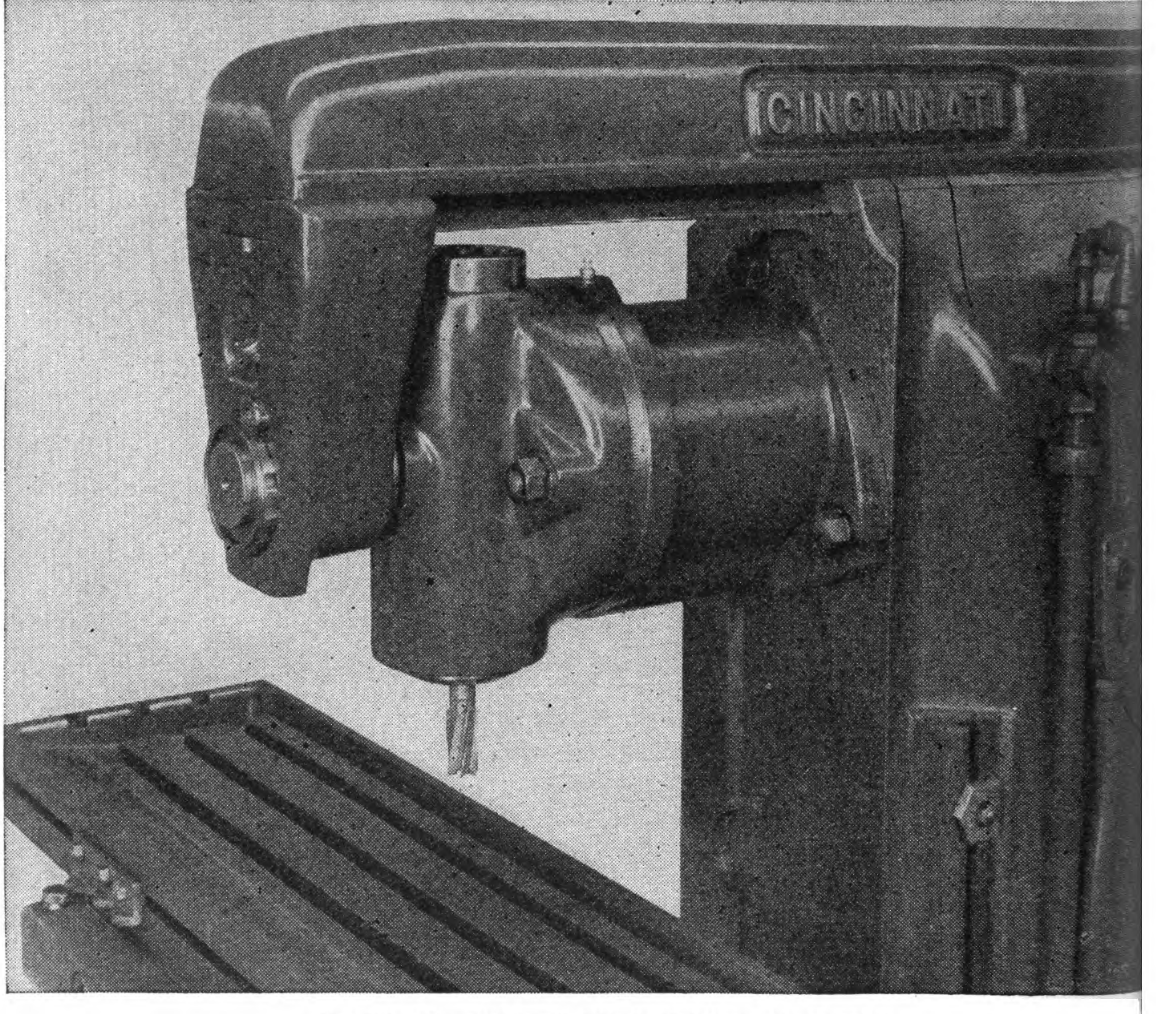


FIGURE 13.—Vertical spindle milling attachment.

(10) *Tilting table* (fig. 18).—The index centers, the vise, or the work can be mounted upon the tilting table when milling tapers.

(11) *Gear cutting attachment* (fig. 19).—The gear cutting attachment is similar to the standard index head and footstock. It is so constructed that large diameter gears may be cut on the milling machine. Standard index plates are adaptable for use with this attachment.

(12) *Coolant system.*—The coolant system consists of a motor driven

centrifugal pump, piping, valves, flexible return pipe, coolant tank, and all necessary connections. The coolant system gives a greater

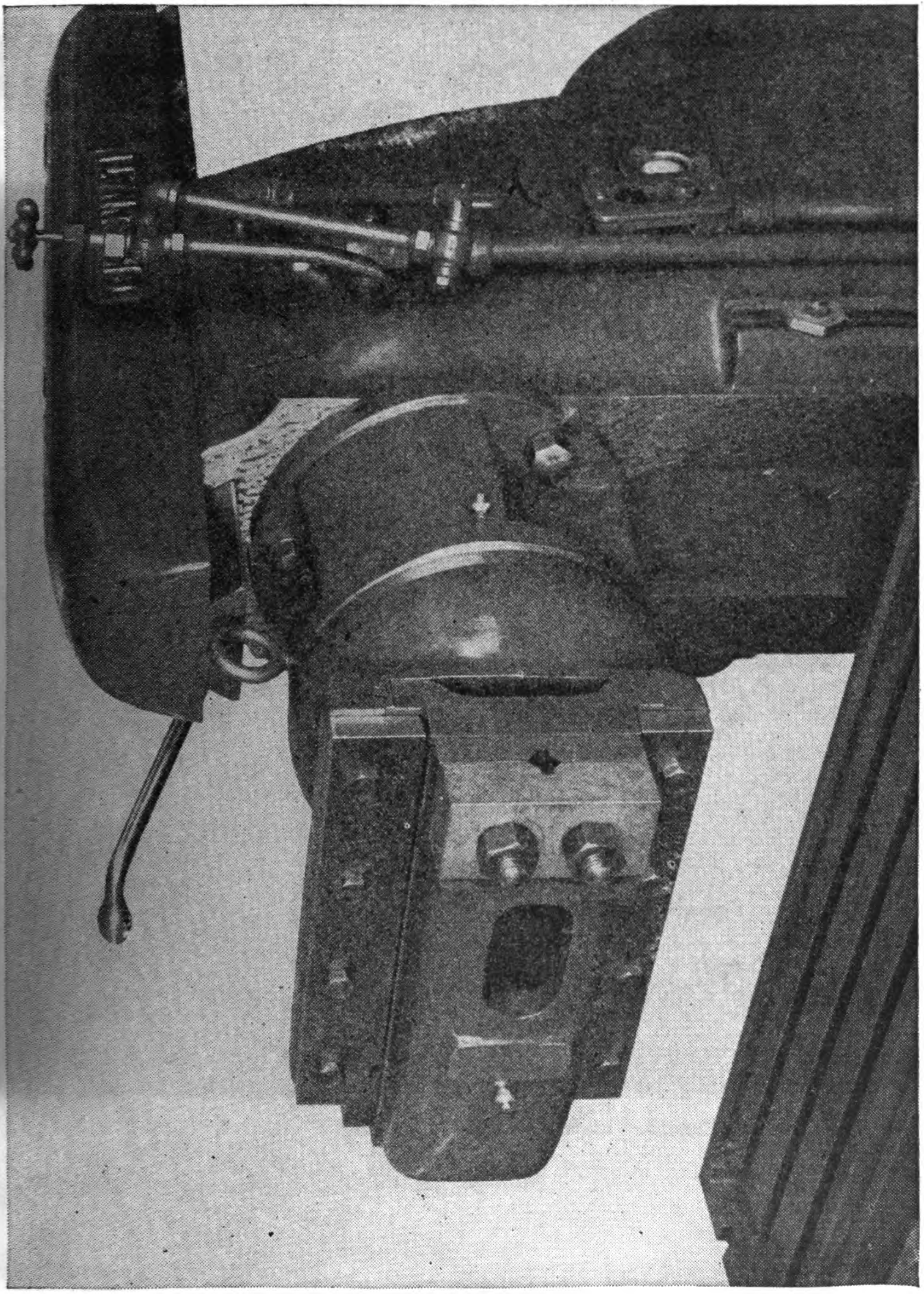


FIGURE 14.—Slotting attachment.

volume of lubricant than the drip can; therefore, higher speeds can be used and better finishes produced.

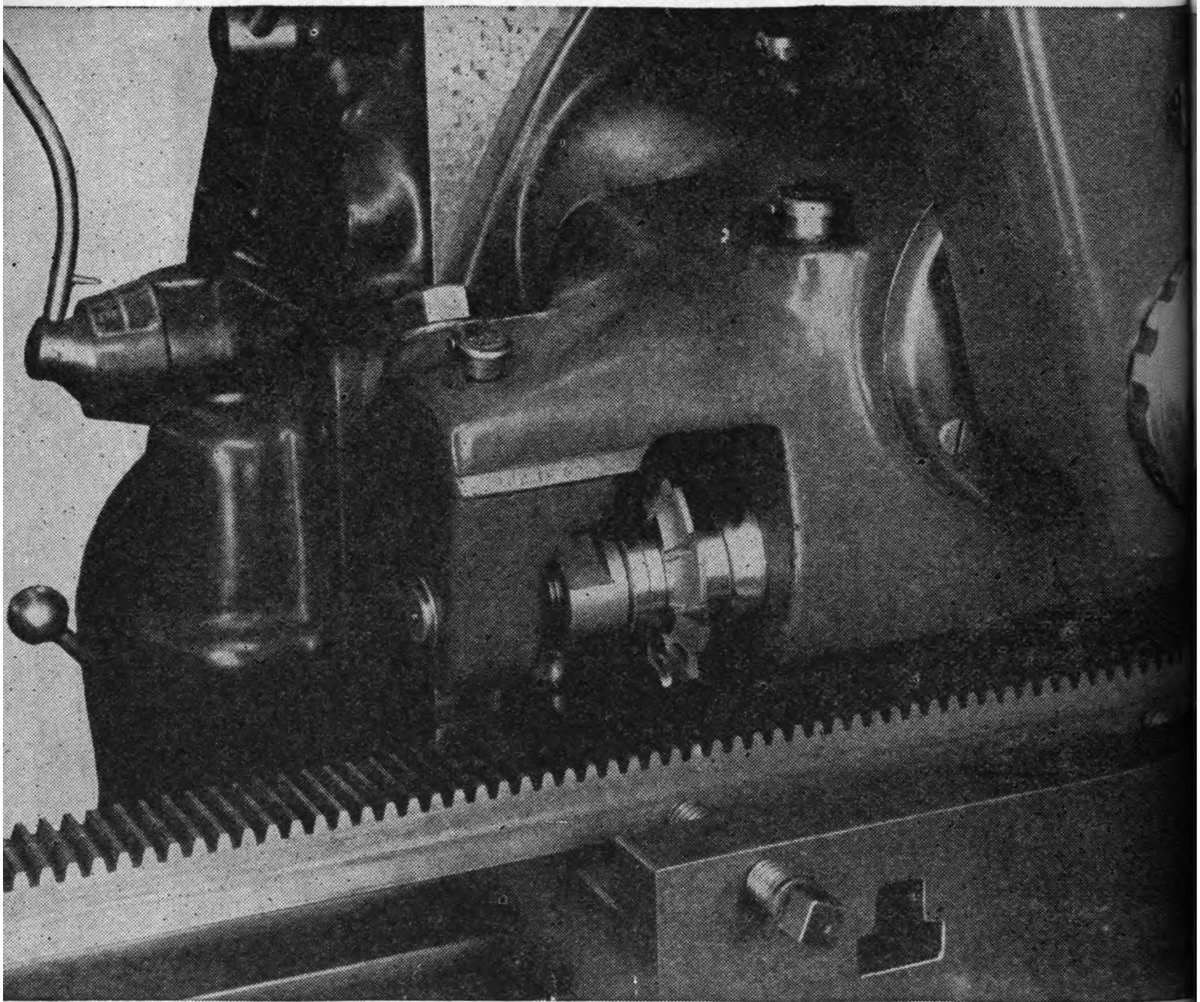


FIGURE 15.—Rack milling attachment.

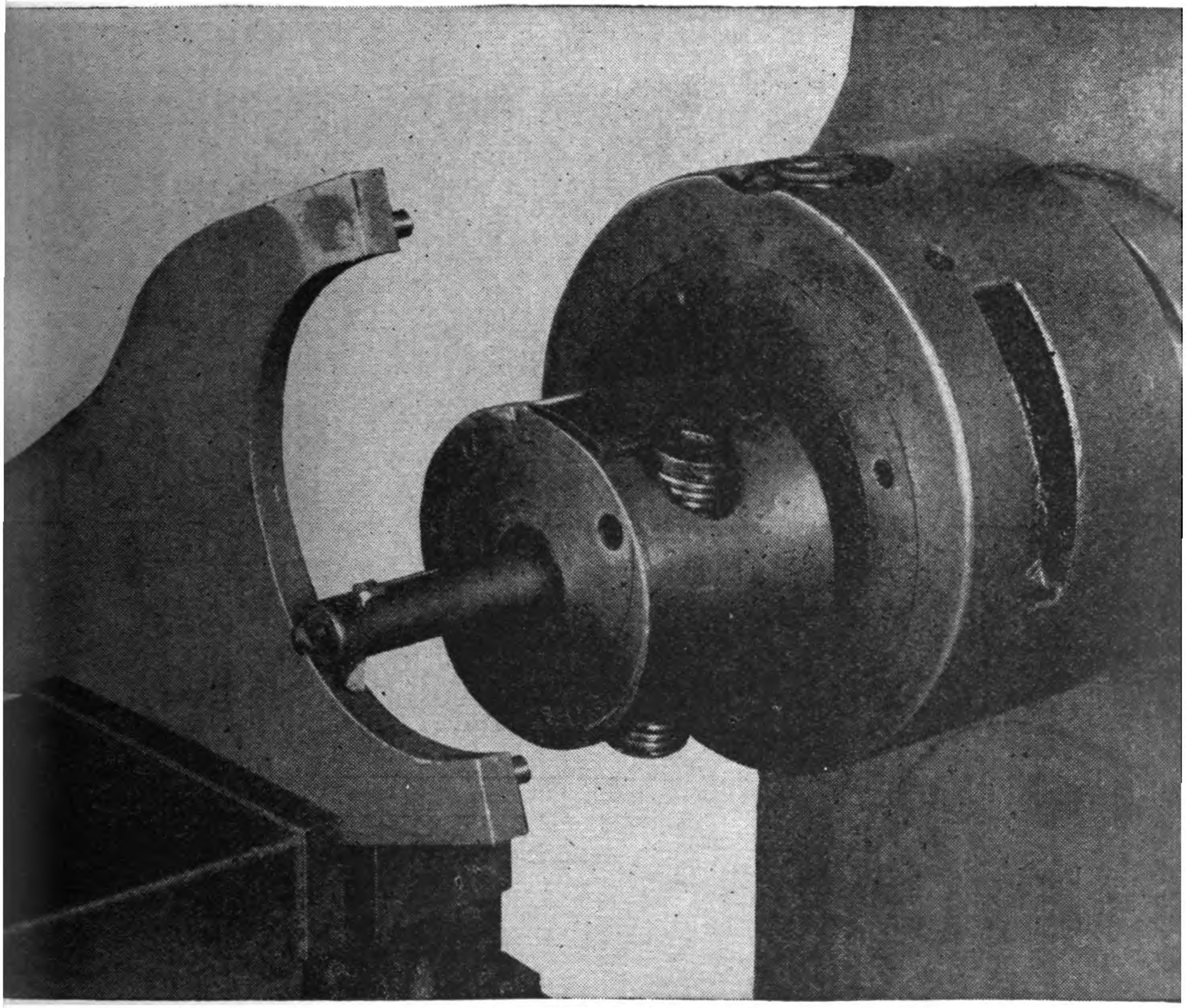
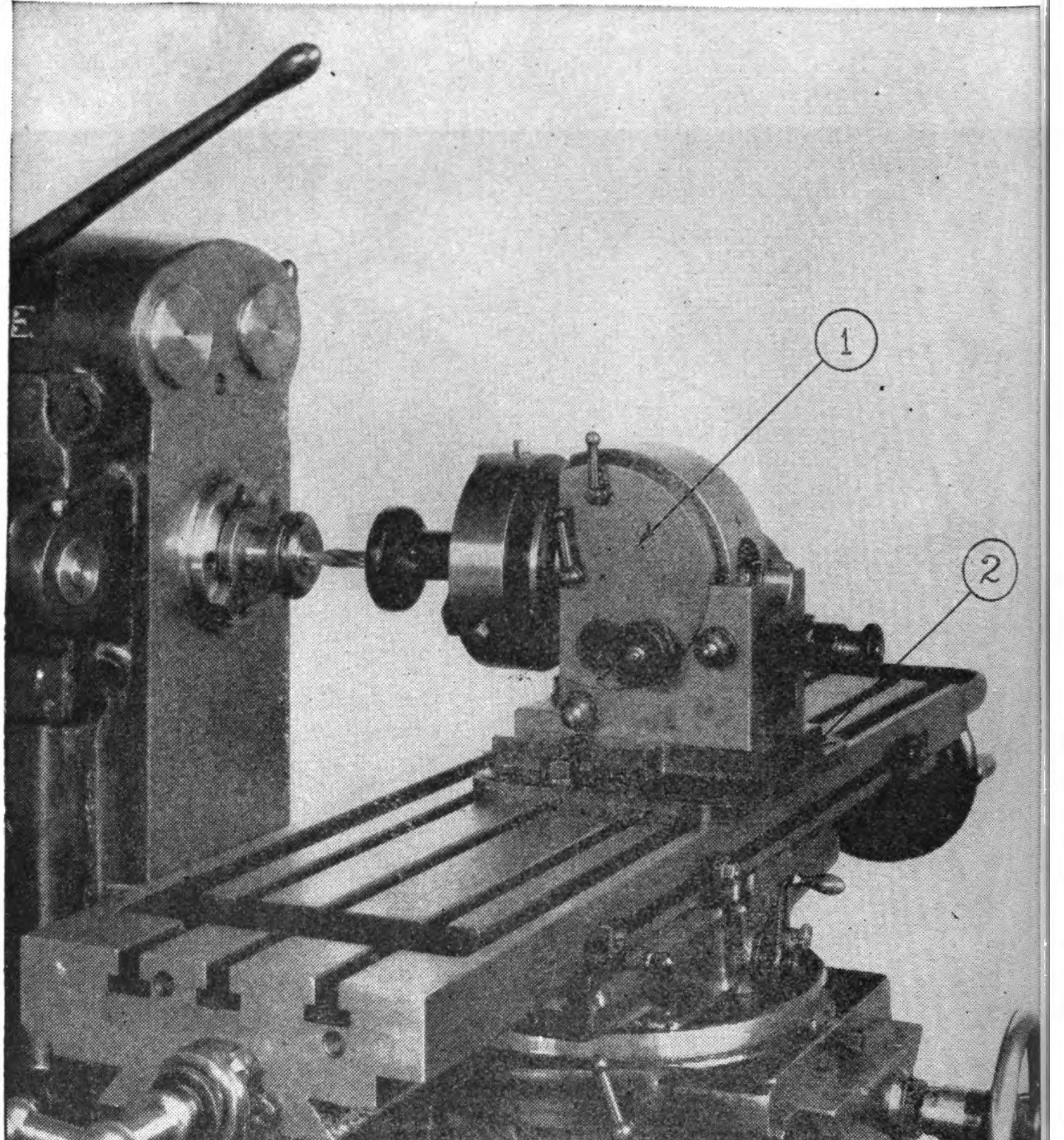


FIGURE 16.—Offset boring head.



1. Index head. 2. Raising block.

FIGURE 17.—Typical application of raising block.

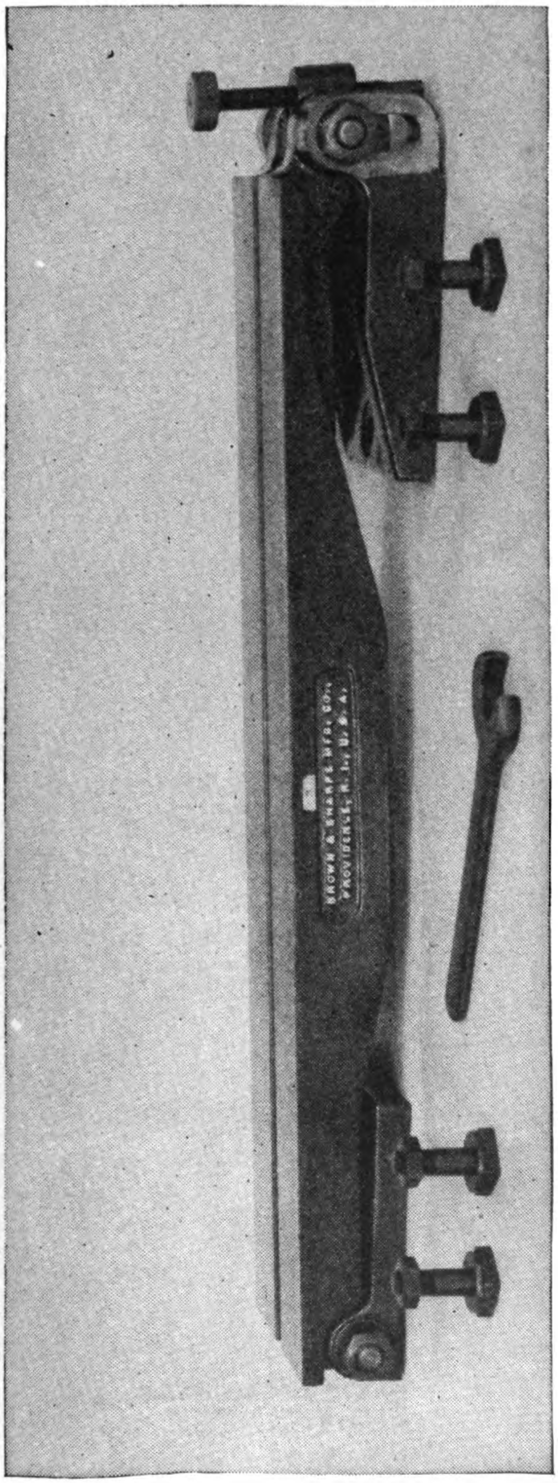


FIGURE 18.—Tilting table.

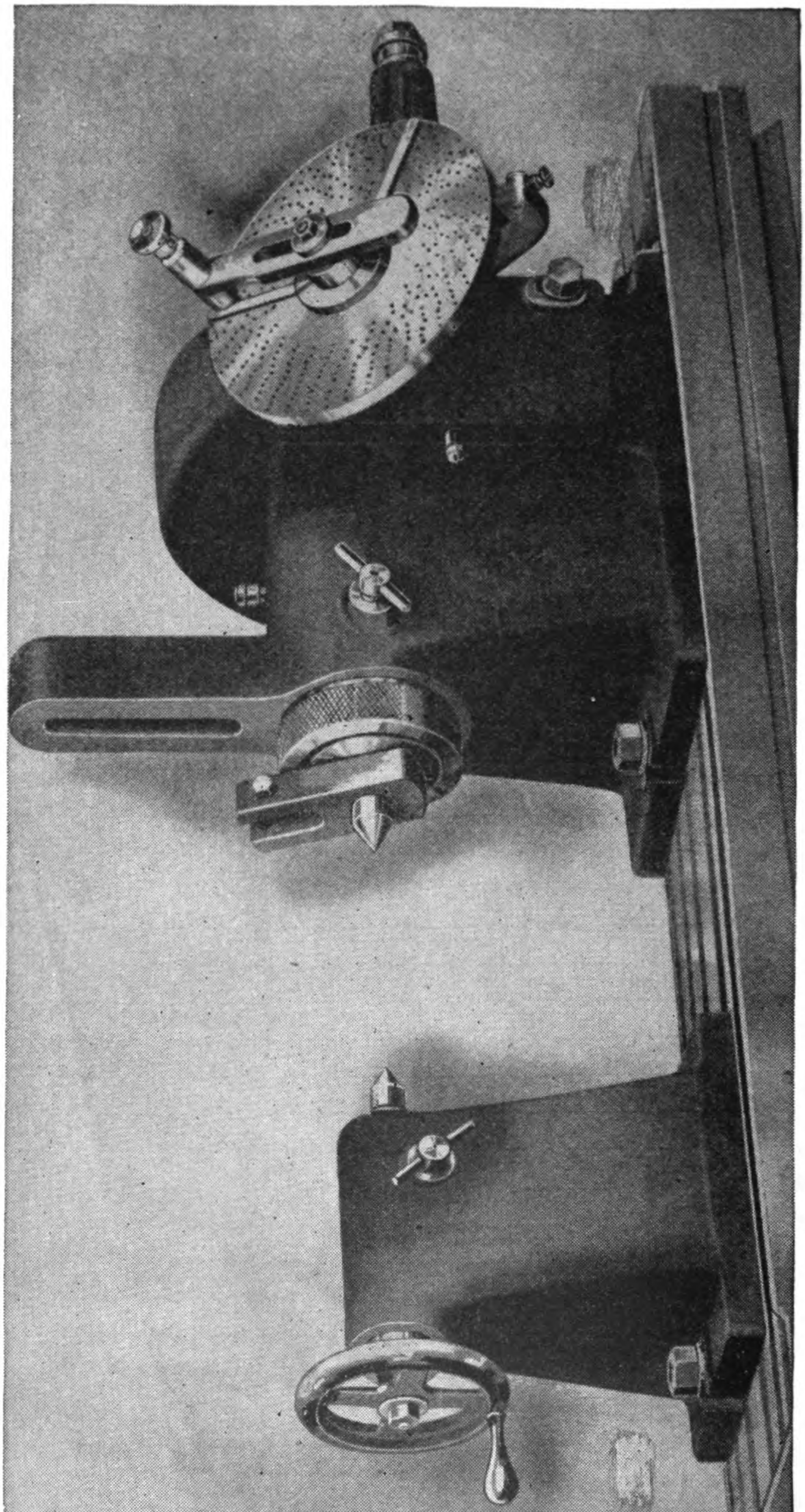
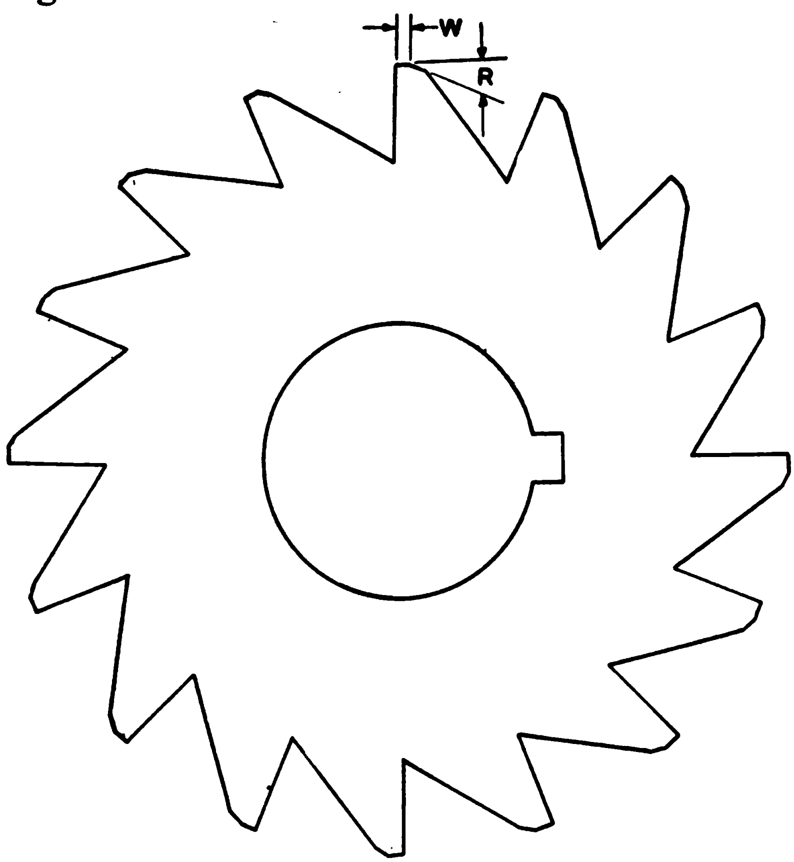


FIGURE 19.—Gear cutting attachment.

SECTION II

MILLING MACHINE CUTTERS

5. Classification of cutters.—Milling cutters may be classified according to the relief of the teeth, hand of rotation, or the method of mounting.

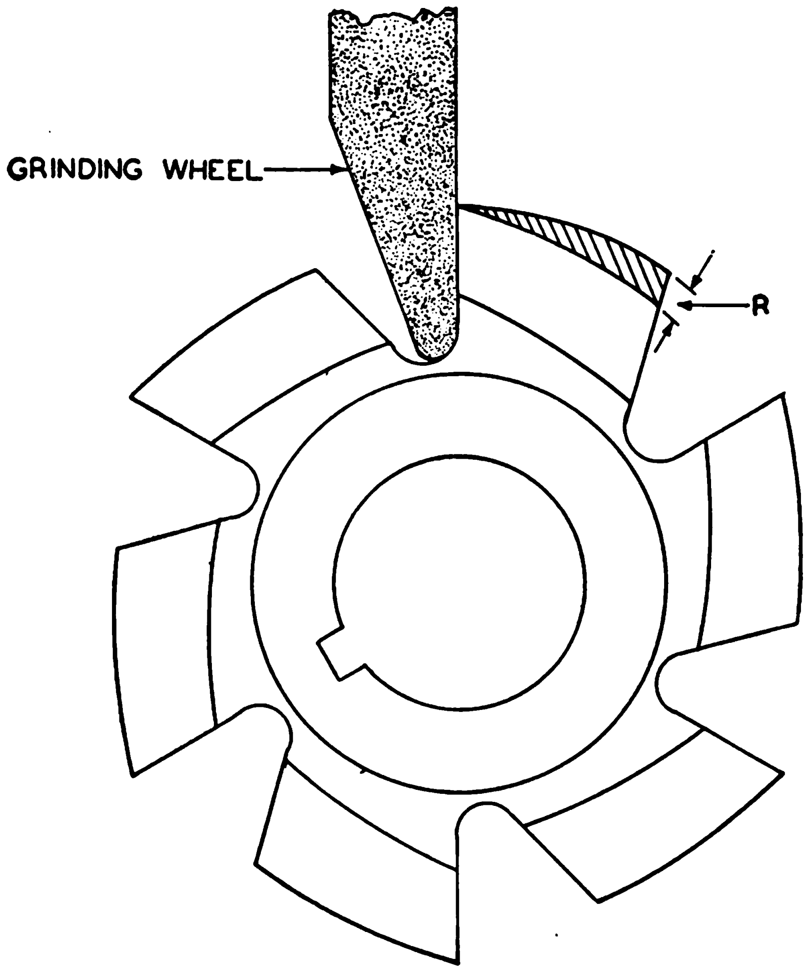


W. Width of land. R. Relief.

FIGURE 20.—Method of sharpening profile cutters.

a. Milling cutters which are sharpened by grinding on the periphery of the teeth and upon which relief is obtained by grinding a narrow land back of the cutting edge, as shown in figure 20, are profile cutters; if they have cutting edges of irregular or curved shape and are sharpened in this manner, they are called shaped profile cutters. Cutters that have eccentric relief back of the cutting edge, that is of the same contour as the cutting edge, are called form cutters. Figure 21 illustrates the correct method of sharpening this type of cutter. As long as the face is ground in the original plane, with respect to its axis, the tooth contour will remain unchanged.

b. The hand of rotation refers to the direction in which the cutter rotates around its axis. This may be determined by looking at the cutter end of the spindle. If it is right hand, it should rotate counter-



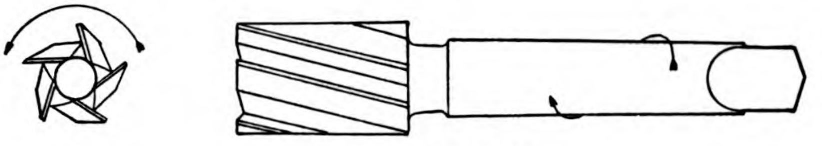
R. Eccentric relief.

FIGURE 21.—Method of sharpening form cutters.

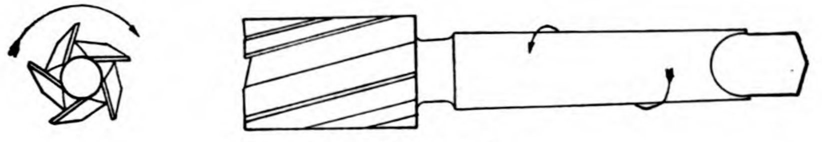
clockwise and if left hand, it should rotate clockwise. Figure 22 illustrates this method of determining rotation.

c. Cutters are also classified according to methods of mounting. Arbor cutters (figs. 23, 24, 26, 28, and 30) are cutters with either a straight, tapered, or threaded hole for mounting upon an arbor. The most common type has a straight hole with a keyway through it or across one end. By means of a key inserted in this keyway, the cutter is prevented from turning on the arbor. Shank cutters (figs. 22, 31, 33 and 34) have straight or tapered shanks and are mounted in collets or adapters. Facing cutters (figs. 10 and 32①) are attached to either a stub arbor or directly to the milling machine spindle.

6. Types of cutters.—Milling cutters are generally made from carbon steel, high speed steel, Stellite, or cemented carbide. The types



① Right-hand cutter.

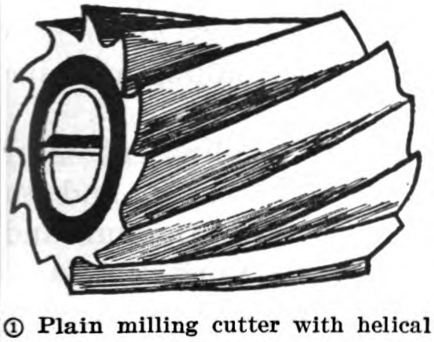


② Left-hand cutter.

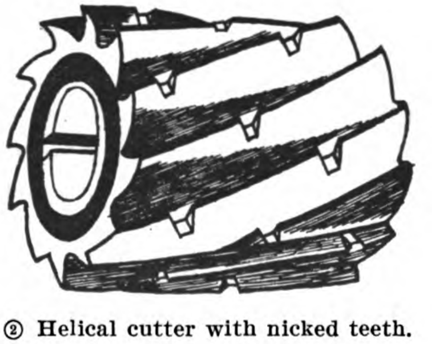
FIGURE 22.—Method of determining hand of rotation.

of cutters most generally used, and the operation to which they are best suited, are given below:

a. The plain milling cutter (fig. 23①) is used for milling flat surfaces that are parallel to the cutter's axis. This cutter is a cylinder with teeth cut upon its circumferential surface only. Plain milling



① Plain milling cutter with helical teeth.



② Helical cutter with nicked teeth.

FIGURE 23.—Plain milling cutters.

cutters are made in a variety of diameters and widths. Although plain cutter teeth may be either straight or helical, the latter type are generally used when the cutter is more than ¾-inch wide. A cutter tooth that is straight or parallel to its axis will cut along its entire width at the same time, causing a shock as the tooth starts to cut. It is to eliminate this shock and produce a freer cutting action that cutters are manufactured with helical teeth. The helical formed tooth, being at an angle, begins the cut at one side and continues across the work with a smooth shaving action.

(1) Plain milling cutters are generally made with radial teeth; however, coarse tooth helical cutters which have the tooth faces under-cut to produce a smoother cutting action are also manufactured. The coarse tooth decreases the tendency for the arbor to spring and gives more chip room, as well as allowing the cutter to have greater strength.

(2) Plain milling cutters for heavy cutting are manufactured with helical teeth that are nicked as shown in figure 23②. These nicks are so staggered that a cutting edge will be behind each nick. The nicked tooth, instead of cutting one continuous shaving, breaks up the chips into a number of separate pieces, one being made by each cutting edge.

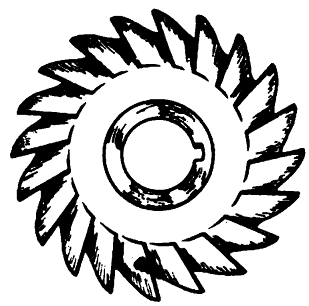


FIGURE 24.—Side milling cutter.

(3) Plain milling cutters are made with a standard size arbor hole so that they may be interchangeably mounted on the milling machine arbor.

b. The side milling cutter (fig. 24), is a plain milling cutter of cylindrical form with teeth on the circumferential surface and on the sides. The sides of the cutter are recessed between the hub and the inner ends of the teeth so that they may clear the work.

(1) Two or more side milling cutters, as shown in figure 25, may be placed on an arbor with a spacing washer between them so as to mill both ends of work to a given dimension. This operation is known as straddle milling.

(2) When milling slots to an exact width, interlocking or staggered tooth side milling cutters, such as shown in figure 26, may be used. Cutters of this type have interlocking teeth so that they may be placed side by side and used as a single cutter. A definite width can be maintained by inserting thin spacers between the two cutters. The

staggered tooth cutter is the most efficient type for milling slots where the depth exceeds the width.

(3) The term "gang cutters" refers to two or more milling cutters mounted on the same arbor, as shown in figure 27, for the purpose

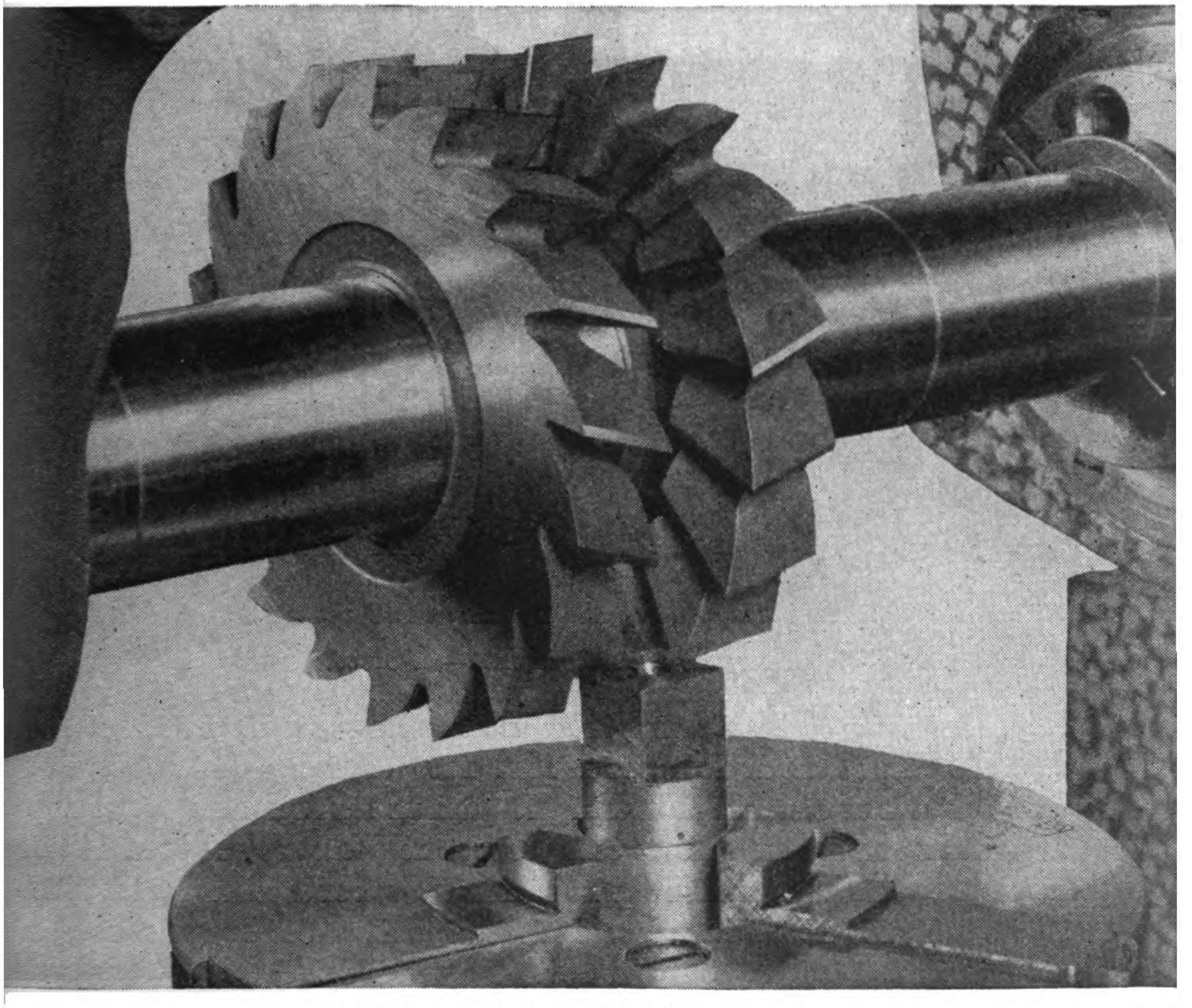
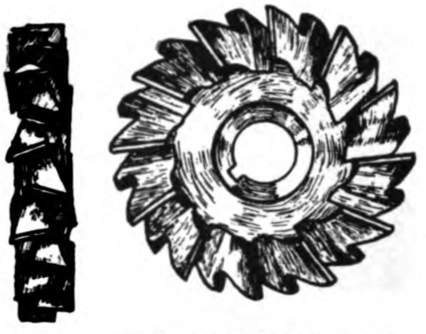


FIGURE 25.—Typical straddle milling operation.

of milling broad surfaces of regular and irregular form. The cutters used for this purpose should have interlocking or overlapping teeth, so that the proper spacing may be obtained.

c. Metal slitting saws (fig. 28) are similar to plain milling cutters and are usually less than 3/16 inch in face width. In general, these cutters have more teeth for a given diameter than plain milling cutters.

① Interlocking type.



② Staggered tooth type.

FIGURE 26.—Slotting cutters.

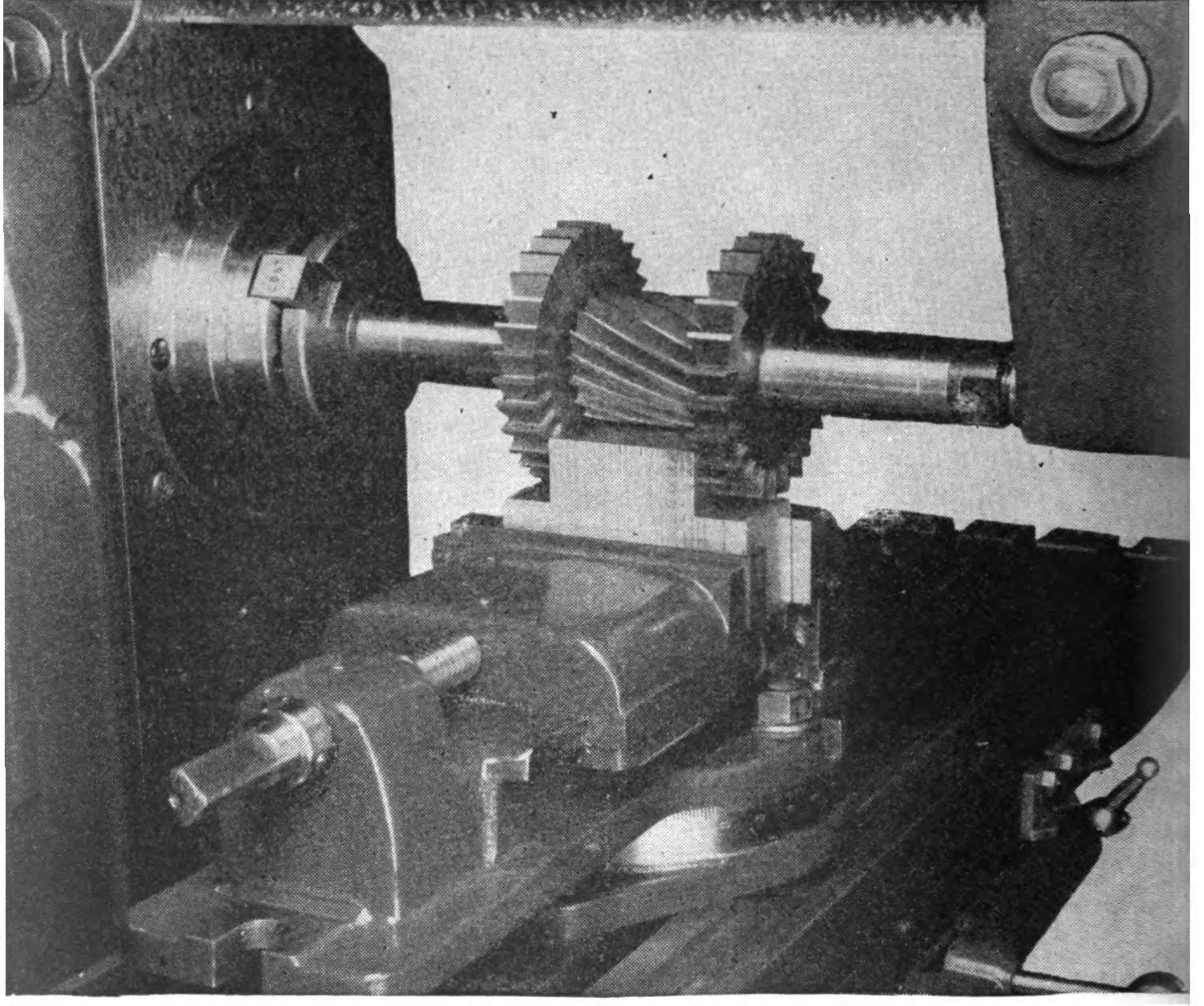


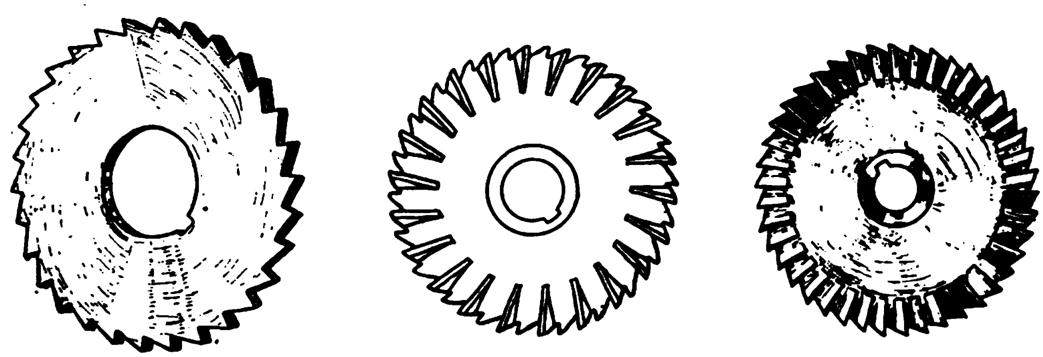
FIGURE 27.—Typical application of gang milling cutters.

Slitting saws are ground slightly thinner at the center for clearance, so that the cutter will not bind when deep slots are cut. They are used to cut off work or to mill very narrow slots. Slitting saws are also made with side teeth, as shown in figure 28③.

(1) For heavy sawing in steel, metal slitting saws with staggered teeth, such as shown in figure 28②, are generally used. Cutters of this type are usually from 3/16 to 3/8 inch thick.

(2) Screw slotting cutters, as shown in figure 29, are used to cut shallow slots such as those in screw heads. These cutters have comparatively fine teeth on their circumferential surface and are made in various thicknesses corresponding to American Standard Gage numbers.

d. When designating plain or side milling cutters, and metal slitting saws, the type and style of tooth, face width, size of hole and diameter



① Plain cutter. ② Staggered tooth cutter. ③ Slitting saw with side teeth.

FIGURE 28.—Metal slitting saws.

should be given. An example of these specifications would be: plain milling cutter, helical tooth, 6-inch face width, 4-inch diameter, and 1-inch hole.

e. Angular cutters are used for cutting surfaces that are not parallel or that are not at right angles to the cutter axis. The single angle cutters are manufactured with straight keyed holes for plain arbor mounting or threaded for mounting on screw arbors. The "screw on" type of angular cutter is used to eliminate arbor interference on such work as the cutting of dovetails. When specifying angular cutters, the type, hand of cutter, outside diameter, thickness, hole size, and angle of cutter should be given. Angular cutters are of two types—single or double.

(1) Single angle cutters (fig. 30①) have teeth forming an oblique angle with one side at 90° to the cutter axis and the other usually 45°, 50°, 60°, 70°, or 80°. Cutters of this type are manufactured for both right- and left-hand rotation and are used for milling the edges

or sides of work to a required angle, or for cutting teeth in milling cutters, clutches, and countersinks.

(2) Double angle cutters (fig. 30②) have two cutting faces which are at an angle to the cutter axis. When both faces are inclined at the same angle to the axis, the cutter is specified by the included angle and when the faces are at different angles by the angle of each side with respect to the plane of intersection. For example, the cutters used for cutting spiral mills are made with a 12° angle on one side and a 40°, 48°, or 53° angle on the other.

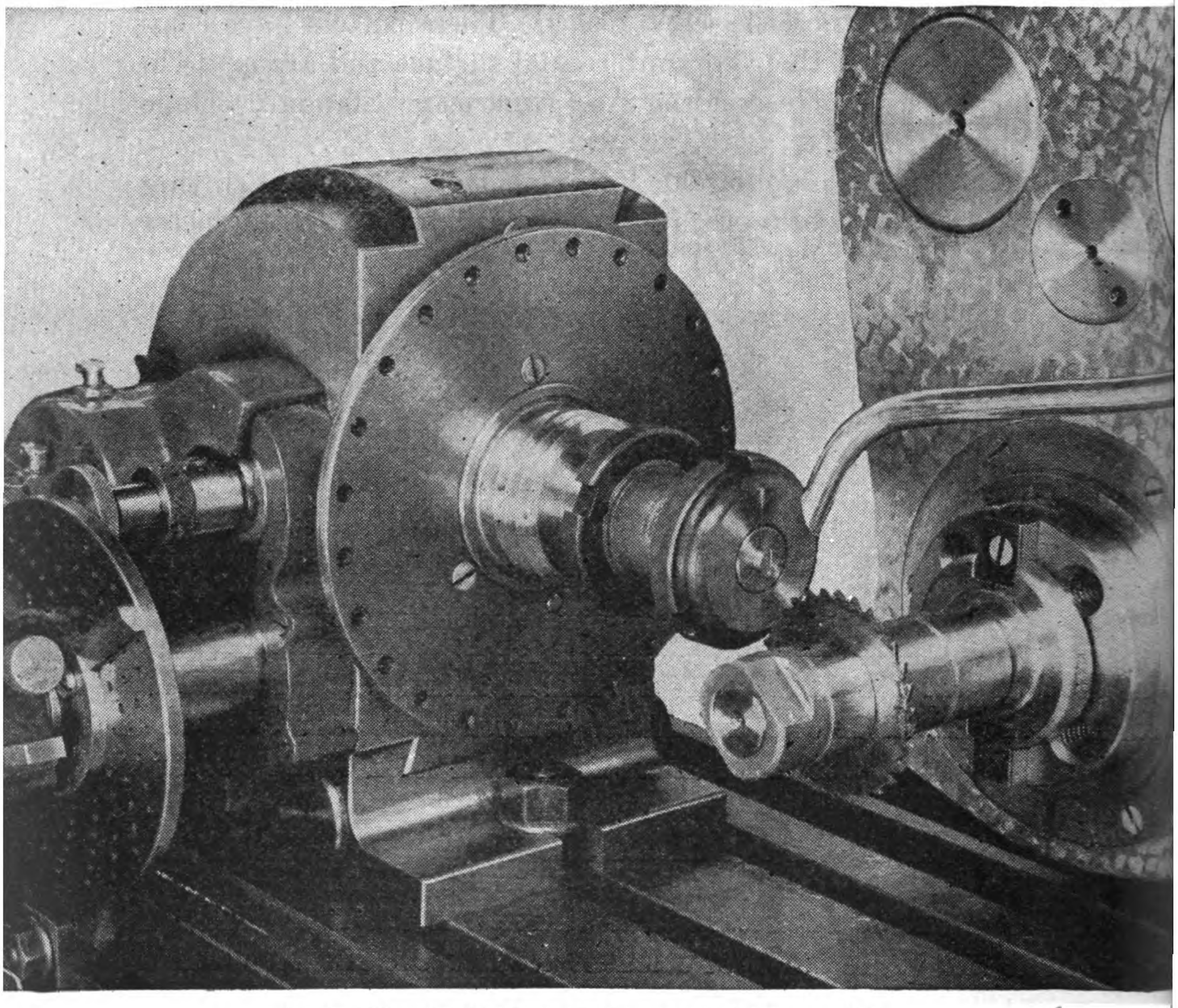


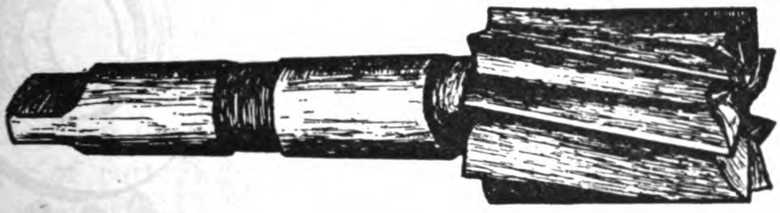
FIGURE 29.—Application of the screw slotting cutter.

(3) Fluting cutters are double angular form tooth cutters with the points of the teeth well rounded. They are generally used for milling the flutes in taps and reamers as shown in figure 71. The fluting cutters are marked with the range of diameters of the taps and reamers for which they should be used.

① Single angle type.

② Double angle type.

FIGURE 30.—Angular cutters.

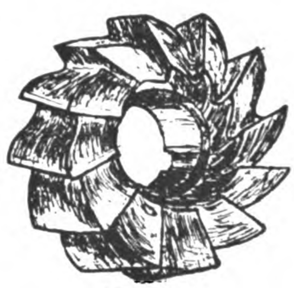


① Center cut-out.

② Two-lipped.

③ Fish tail.

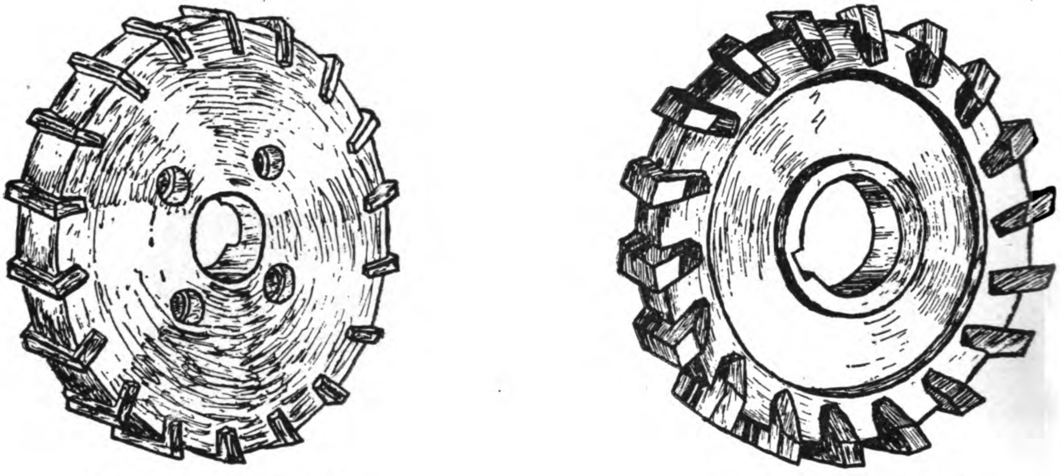
④ Hollow.



⑤ Shell.

FIGURE 31.—End mills.

f. End mills are employed in the production of slots, squares, and tangs, and may also be used for milling the edges of work. They have teeth on one end, as well as on the circumferential surface. End mills are manufactured with straight or helical teeth and for either right- or- left-hand rotation; the commonly used types are illustrated in figure 31.



① Face milling cutter. ② Side milling cutter.

FIGURE 32.—Inserted tooth milling cutters.

FIGURE 33.—T-slot cutter.

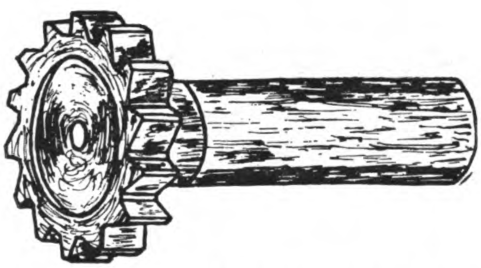


FIGURE 34.—Woodruff keyseat cutter.

(1) Center cut-out end mills (fig. 31①) are used to cut into the work to a depth equal to the length of the end teeth. The use of this type of cutter dispenses with the necessity of drilling a hole as must be done when the inner sides of the teeth are not relieved.

(2) Two-lipped end mills (figs. 31②) are especially adaptable for the rapid milling of slots, as this tool does not necessitate the drilling

of a starting hole. A high surface speed is necessary to secure the best results with this cutter.

(3) Fish tail cutters (fig. 31③) are generally used for milling grooves in shafts where the groove does not exceed ¼ inch in width. When using this type of cutter the machine should be set for a fine feed and light cut.

FIGURE 35.—Involute gear cutter.

(4) Hollow mills (fig. 31④) are cutters of tubular construction, having teeth on one end, which are ground with internal clearance. This type of cutter is generally used for producing bosses or cylindrical projections on solid stock.

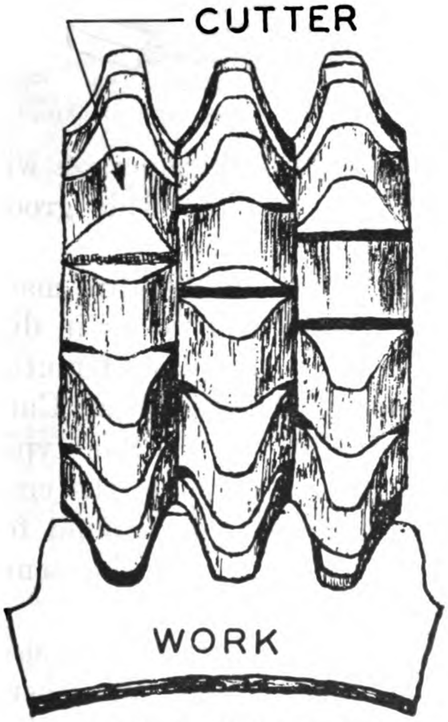


FIGURE 36.—Multiple gear cutter.

(5) Shell type end mills (fig. 31⑤) are shouldered at the front for the head of the screw which fastens them to the arbor. A slot on the back of the cutter engages a driving key which prevents the cutter from turning on its mounting. This cutter is cheaper to

replace than other types and, therefore, should be used whenever possible.

(6) Face milling cutters (figs. 10 and 32①) are cutters that are attached directly to the milling machine spindle or stub arbor. They have inserted teeth of high speed steel, Stellite, or steel tipped with cemented carbide. The teeth are usually held in place by taper bushings and screws and can be easily adjusted or removed.

g. The T-slot cutter (fig. 33) is similar in form to the side milling cutter, having teeth on the circumferential surface and on both sides. It is made with a solid taper shank and is provided with few teeth, so as to leave plenty of chip room. The teeth are generally staggered so that each tooth cuts with one side only. T-slot cutters are used for milling slots to receive bolt heads and are made in standard dimensions to suit bolts of various sizes. In cutting a T-slot, a plain

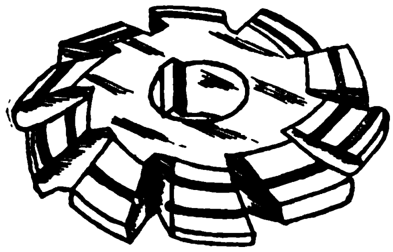


FIGURE 37.—Gear cutter stocking.

groove is generally milled slightly undersize with a two-lipped end mill or side milling cutter, and the wide groove at the bottom is then machined with the T-slot cutter.

h. Woodruff keyseat cutters (fig. 34) are made in both the shank and arbor types. Those under 1½ inches in diameter are provided with a shank and have teeth on the circumferential surface, with their sides ground slightly concave for clearance. Cutters, larger than 1½ inches in diameter, are usually of the arbor type. These larger cutters ordinarily have staggered teeth on the circumferential surface and on the sides. The side teeth are ground for clearance and not for cutting. Both types are used for cutting semicylindrical keyways in shafts.

i. Gear cutters (fig. 35) are form cutters used for milling gear tooth spaces. They are manufactured for either the involute or epicycloidal type of tooth. The Brown and Sharpe involute cutter system involves the use of eight cutters, numbering from 1 to 8, which will accommodate each of the various pitches. The epicycloidal type cutter has a double curve form of tooth and due to the exact center distance required, is made with a small shoulder which limits the depth that the gear tooth can be cut.

(1) The multiple gear cutter (fig. 36) may be a single unit form cutter or two or more form cutters, placed together and used to mill two or more gear tooth spaces during one pass.

(2) The gear cutter stocking (fig. 37) is a form cutter, the teeth of which are provided with staggered grooves. Due to the chip-

FIGURE 38.—Typical concave and convex cutters.

breaking action of these grooved teeth, heavy cuts can be taken at fast speeds and feeds. These grooves are staggered in such a manner as to produce a smooth finish.

(3) Stub gear cutters are used for cutting stub toothed gears which are thicker and not so deep as the involute tooth gear.

(4) Bevel gear cutters are used for cutting the gear spaces on bevel gears and pinions, their size being designated by the diametral pitch.

j. Concave and convex cutters (fig. 38) are used to cut convex and concave surfaces or contours equal to a half circle or less. Their size is specified by the diameter of their circular form.

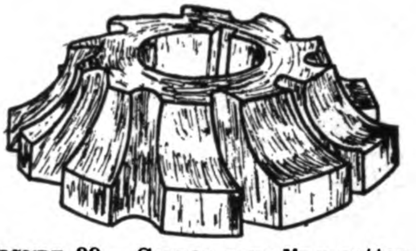


FIGURE 39.—Corner rounding cutter.

k. Corner rounding cutters (fig. 39) are formed cutters used for milling rounded corners on work up to and including one quarter of a circle.

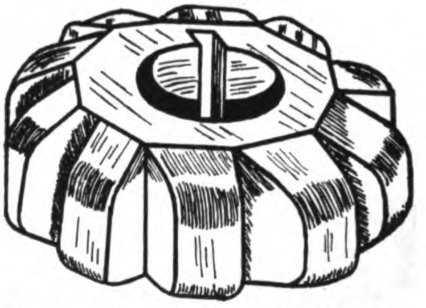


FIGURE 40.—Sprocket wheel cutter.

l. Sprocket wheel cutters (fig. 40) are used for milling teeth on sprocket wheels. Like other formed cutters, their outline is not changed by grinding.

FIGURE 41.—Gear hob.

m. The gear hob (fig. 41) is a formed milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. Hobs are generally used for such work as finishing spur gears, spiral gears, worm wheels, etc., and may also be employed for cutting ratchets and spline shafts.

n. The fly cutter is a special cutter that may be used on work where a standard cutter is not available. As shown in figure 91, the cutter is securely held in an arbor which is driven by the milling machine spindle. The fly cutter may be ground to any desired shape and is used as a revolving cutter, by feeding the work slowly into it, or as a stationary cutter for finish-scraping work which is fed past it.

o. Inserted tooth cutters, such as those illustrated in figure 32, have inserted cutting teeth of high speed steel, Stellite, or carbide tipped steel, secured by various methods, in a body of less expensive material. This feature allows tooth replacement and therefore reduces the cost of upkeep. These cutters are usually made to cut on both the circumferential surface and side as in the case of the side mill. Inserted tooth cutters may be applied to an arbor or attached directly to the milling machine spindle end.

7. Selection of cutters.—Factors to be considered in the choice of milling cutters are as follows:

a. Type of machine to be used.—High speed steel, Stellite, and cemented carbide cutters have the distinct advantage of being capable of rapid production when used on a machine which can reach the proper speed.

b. Method of holding the work.—For example, 90° angular cuts may either be made with a 90° angular cutter, while the work is held in a plain vise, or with an end mill, while the work is set at the required angle in a universal vise.

c. Hardness of the material to be cut.—The harder the material, the greater the heat that is generated in cutting. Cutters should be selected for their heat resisting properties.

d. Amount of material to be removed.—A coarse-toothed cutter should be used for roughing cuts, whereas an ordinary spiral milling cutter may be used for light cuts and finishing operations.

e. Number of pieces to be cut.—For example, when milling stock to length, the choice of using either a pair of straddle mills or a side or end mill will depend upon the number of pieces to be cut.

f. Class of work being done.—Some operations can be accomplished with more than one type of cutter, for example, milling the square end on a shaft or reamer shank. In this case a side milling cutter, straddle mill, or an end mill may be used. However, for the majority of work, cutters are especially designed and named for the operation they are to accomplish.

g. Rigidity and size of the work.—The cutter used should be small enough in diameter so that the pressure of the cut will not cause the work to be sprung or displaced while being milled.

h. In selecting a cutter for a particular job, it should be remembered that a small diameter cutter will pass over a surface in a shorter time than a large diameter cutter fed at the same speed. This fact is illustrated in figure 42.

8. Care and maintenance of cutters.—The life of a milling cutter can be greatly prolonged by intelligent use and proper storage. General rules for the care and maintenance of milling cutters are given below.

a. New cutters received from the manufacturer are usually wrapped in oil paper which should not be removed until the cutter is used.

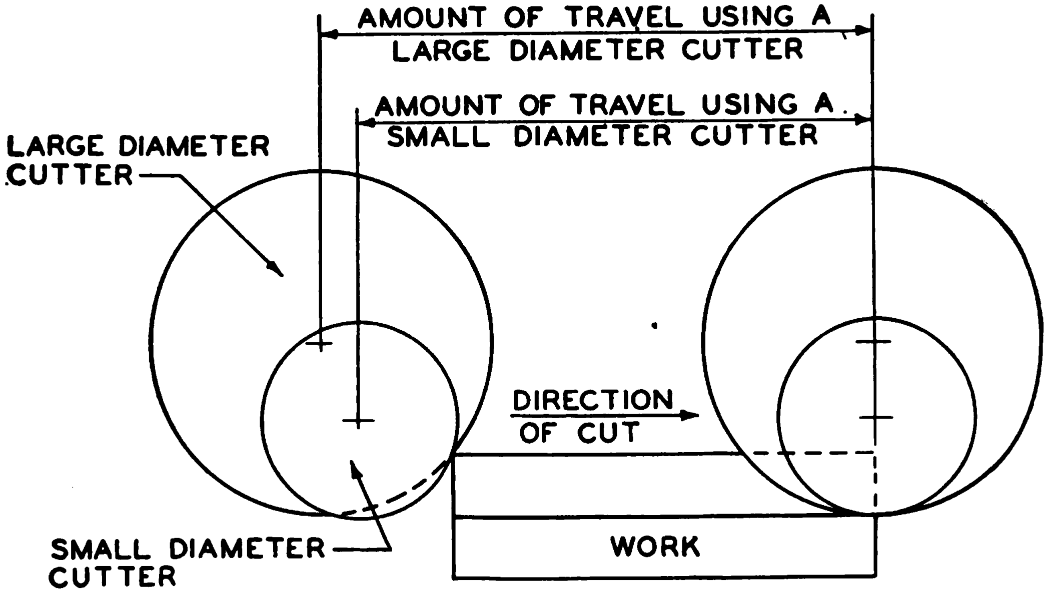


FIGURE 42.—Method of selecting cutter diameter.

b. Care should be taken to operate the machine at the proper speed for the cutter being used, as excessive speed causes the cutter to wear rapidly from overheating.

c. Whenever it is practicable, the proper lubricant should be used on the cutter during operation, as lubrication helps prevent overheating and consequent cutter wear.

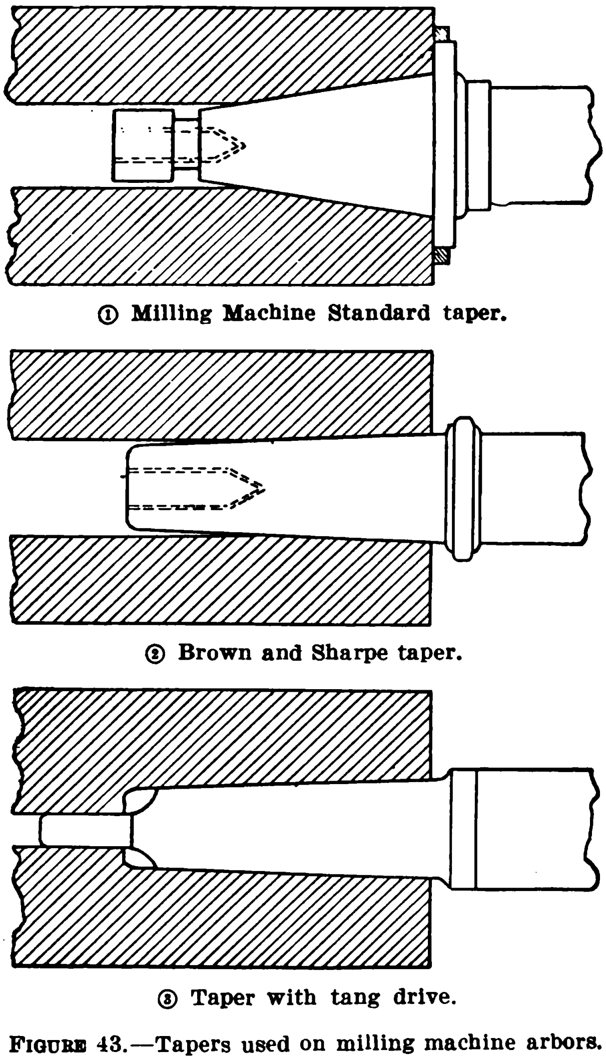
d. Cutters should be kept sharp, as dull cutters require more power to drive, and this power being transformed into heat softens the cutting edges. Dull cutters should be marked as such and set aside for grinding.

e. A cutter should never be operated backward because, due to the clearance angle, the cutter will rub, producing a great deal of frictional heat.

f. Care should be taken to prevent the cutter from striking the hard jaws of the vise, chuck, clamping bolts, or nuts.

g. A cutter should be thoroughly cleaned and lightly coated with oil before storing.

h. Cutters should be placed in drawers or bins in such a manner that their cutting edges will not strike each other. Small cutters that have a hole in the center should be hung on hooks or pegs, while large cutters should be set on end. Taper and straight shank cutters may be placed in separate drawers, bins, or racks provided with suitable sized holes to receive the shank.



① Milling Machine Standard taper.

② Brown and Sharpe taper.

③ Taper with tang drive.

FIGURE 43.—Tapers used on milling machine arbors.

9. Methods of mounting cutters.—Cutters may be mounted directly to the milling machine spindle or attached to it by means of various devices such as arbors, adapters, collets and spring chucks.

a. Arbor mounting.—There are several types of cutter arbors in general use, each being particularly adapted to certain operations.

(1) These arbors may have any one of the three tapers shown in figure 43.

(*a*) The Milling Machine Standard taper (fig. 43①) is generally used on recently manufactured equipment and was originated by milling machine manufacturers to facilitate removal of the arbor from the spindle.

(*b*) The Brown and Sharpe taper (fig. 43②) is found mainly on older machines and may be any of several sizes. Should it be necessary to use this type of taper on a machine whose spindle has a Milling Machine Standard taper, an adapter or collet will be required.

(*c*) The taper shown in figure 43③ is also used to a certain extent on older machines and is provided with a tang on the shank which assists in driving by engaging a slot in the spindle.

(2) The Milling Machine Standard and Brown and Sharpe tapered arbors are usually driven by means of the taper, supple-

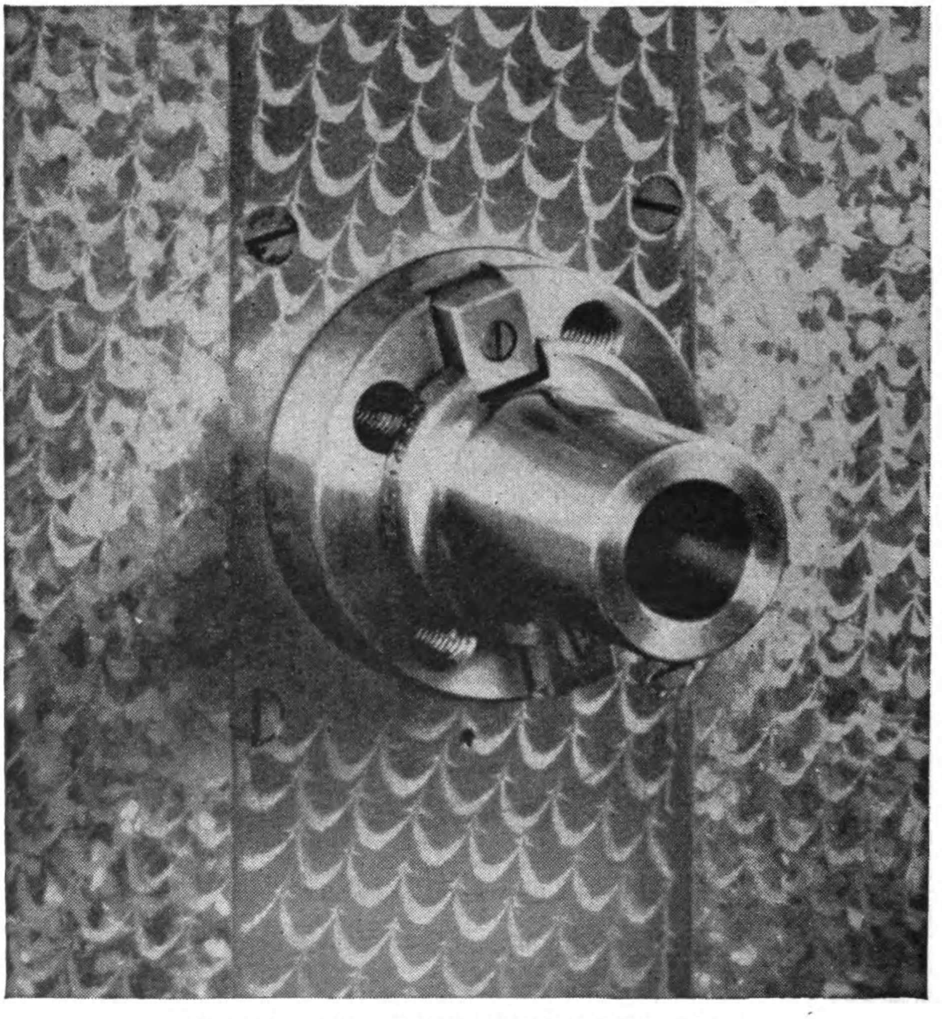


FIGURE 44.—Key arrangement for driving arbors.

mented by a key arrangement, shown in figure 44. This key device is manufactured as a part of the arbor and milling machine spindle. The arbors are held in the milling machine by a draw-in bolt, such as illustrated in figure 45, which traverses the length of the spindle and has a threaded portion that fits into the small end of the arbor's tapered shank. To remove an arbor held in this way, it is necessary to loosen the draw-in nut a part of a turn and tap the head of the bolt lightly. An arbor, having the tanged shank, is applied to the spindle by placing the tang into the spindle slot, and drawing it up tightly with the draw-in bolt. Removal of this type of arbor is accomplished in the same manner as described for the keyed types.

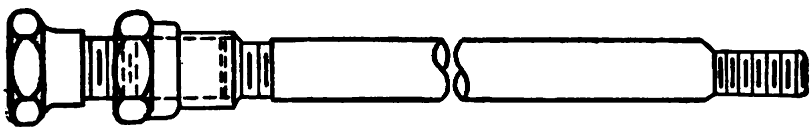
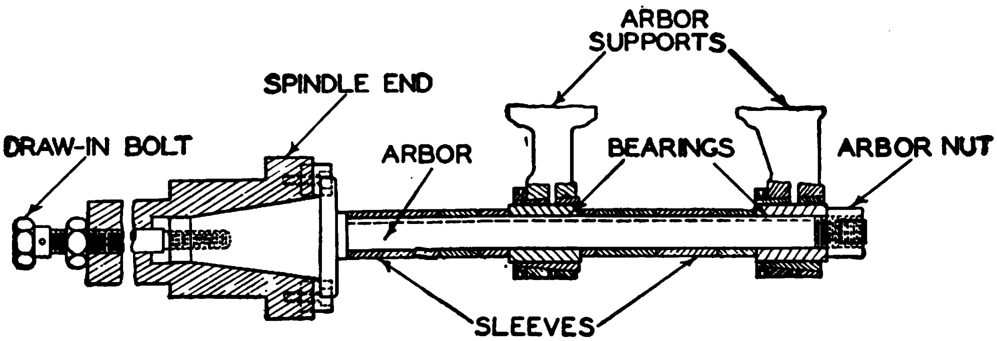


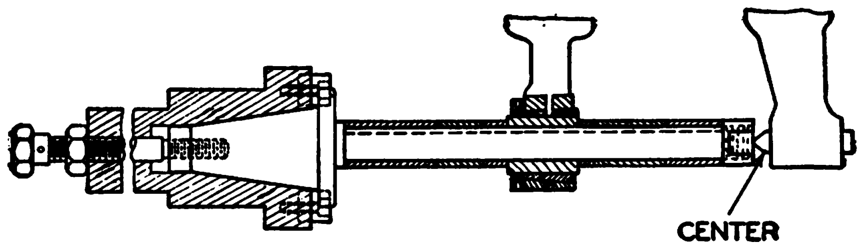
FIGURE 45.—Draw-in bolt.

(3) The various types of arbors may be described as follows:

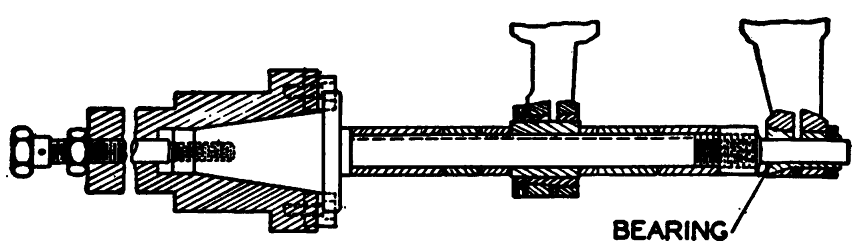
(*a*) The Standard Milling Machine arbor, with the exception of the tapered or drive end that is inserted into the spindle, is of



① Support by means of bearings.



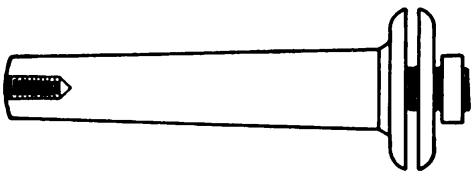
② Support by means of center and bearings.



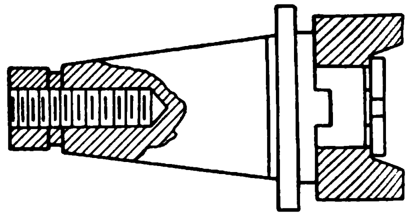
③ Support of arbor with undercut end.

FIGURE 46.—Methods of supporting straight arbors.

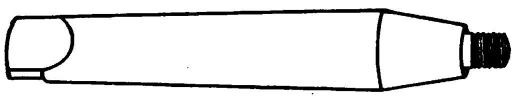
straight cylindrical shape, having a threaded portion on the end opposite the taper to receive the arbor nut. One or more cutters may be spaced and clamped on the straight cylindrical portion of the arbor by means of sleeves and the arbor nut. Arbors of this type, as illustrated in figure 46, are made in standard diameters and of various lengths. The Standard arbor is usually splined for keys to give a more positive drive to the cutter. Sleeves or collars, as shown in the illustration, are used in connection with the arbor for holding the cutter in place, and are made of steel, hardened and ground to size. Sleeves of various lengths and diameters are supplied to fit the arbor on which they are to be used. Thin metal spacers are occasionally used with the larger sleeves when it is necessary to place more than one cutter on the arbor. The thicknesses of these thin spacers vary from 0.002″ to 0.0625″.



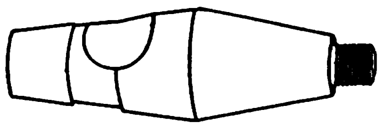
① Screw slotting arbor.



② Shell end mill arbor.



③ Tanged screw arbor.



④ Cam lock screw arbor.

FIGURE 47.—Special arbors.

(*b*) Arbors for holding shell end and face milling cutters are those on which the cutter is held by a screw at the end of the arbor and driven by a tongue that fits into a radial slot at the back of the cutter. This arbor, as illustrated in figure 47②, is inserted into the milling machine spindle and held by the taper and draw-in bolt.

(*c*) The fly cutter arbor is made in various shapes to accommodate the size and shape of the cutter to be used. An application of this type of arbor is shown in figure 91.

(*d*) The screw slotting cutter arbor (fig. 47①) is a short arbor having two flanges between which the cutter is secured by tightening the clamping nut. This arbor is manufactured to hold cutters used for slotting and sawing purposes.

(*e*) Screw arbors are used to hold small cutters that have threaded holes. These arbors, which are illustrated in figure 47③ and ④, have a flanged and threaded end. A right-hand threaded arbor must be used for right-hand cutters while a left-hand threaded arbor must be used for left-hand cutters.

(4) The arbor support (fig. 46①) should be used to prevent springing when the cutter is mounted on a long arbor, although one is not required with the short arbors that place the cutter near the column of the machine. The support is fastened to the overarm of the milling machine and should be located as close to the cutter as possible. Attachment is made to the arbor in one or more of the following ways:

(*a*) By the use of a bearing on the arbor. As shown in figure 46①, this bearing forms a journal that fits into a bushing in the arbor support.

(*b*) When it is not practicable to use the above method, the arbor may be supported by means of an arbor support, which has a 60° point that can be inserted in the center hole of the arbor, as shown in figure 46②.

(*c*) Some types of arbors have a bearing surface cut on the end opposite the tapered shank. This bearing surface fits into a bearing in the arbor support, as shown in figure 46③.

(5) The following procedure should be used to assure correct mounting of arbors and cutters:

(*a*) The arbor hole and arbor shank should be thoroughly cleaned. If it is found that the arbor or spindle hole is burred or scored, it should be scraped, filed, or reamed to remove the burred or scored areas.

(*b*) The taper shank of the arbor should then be inserted in the milling machine spindle and the arbor held in place by the taper and draw-in bolt.

(*c*) The cutter and sleeves should be thoroughly cleaned before mounting upon the arbor.

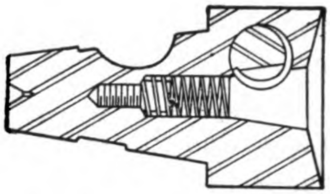
(*d*) The hole in the cutter and sleeves should provide a sliding fit on the arbor.

(*e*) In order to obtain maximum efficiency in operating the cutter, it should be mounted as nearly true as possible and as close to the column of the milling machine as the work will permit. Attention to this detail will help to eliminate spring in the arbor.

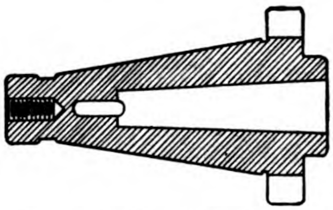
(*f*) The cutter is placed in position on the arbor by means of sleeves of varying lengths. After positioning the cutter, the arbor nut should be drawn up by hand and the arbor support (if required) adjusted and locked in position. The arbor nut is then drawn up tightly with a wrench. Failure to use the arbor support while tightening or loosening the nut will spring the arbor out of alinement, making it useless.

b. Adapters, collets, and spring chucks are generally used to drive and hold end mills, drills, and chucks that have straight or tapered shanks.

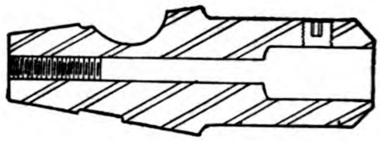
(1) Adapters are manufactured with both Milling Machine Standard and Brown and Sharpe tapered shanks. These adapters are inserted into the milling machine spindle and held in place with a



① Cam lock cutter adapter.



② Tanged cutter adapter.

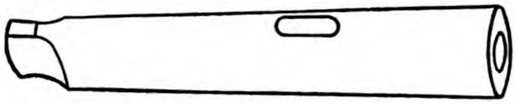


③ Straight shank cutter adapter.

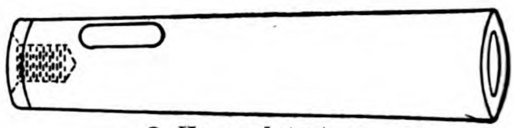
FIGURE 48.—Spindle adapters.

draw-in bolt. The cutter may be driven and held in the adapter in any of the following ways:

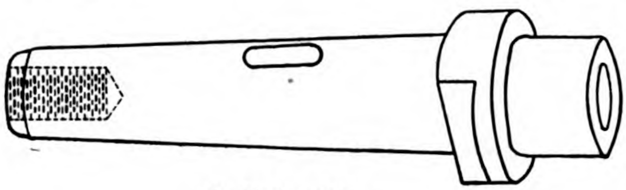
(*a*) Cutters and arbors with tapered shanks featuring the cam lock arrangement are held in the cutter adapter as shown in figure 48①. These adapters have the Milling Machine Standard taper hole,



① Tanged type.



② Heavy duty type.



③ Plain type.

FIGURE 49.—Collets.

and a cam lock is used to hold the cutter. A spring in the bottom of the tapered hole assists in removing the cutter from the adapter.

(*b*) Arbors and cutters with taper shanks, other than those having the cam lock feature, are usually held in adapters of the type illustrated in figure 48②. These adapters have a tapered hole to accommodate one of the various tapers and are often used in combination with collets.

(2) Collets serve the purpose of "stepping up" or increasing taper sizes. They are similar in most respects to drill press sockets, the difference lying in the fact that their tapers are unlike. Figure 49 illustrates the various types in general use.

(3) Spring chucks (fig. 50) generally consist of a collet adapter that is inserted into the milling machine spindle, a spring collet, and a clamping device. The collets are made to close concentrically by means of a draw-in rod or cap nut that forces the jaws against

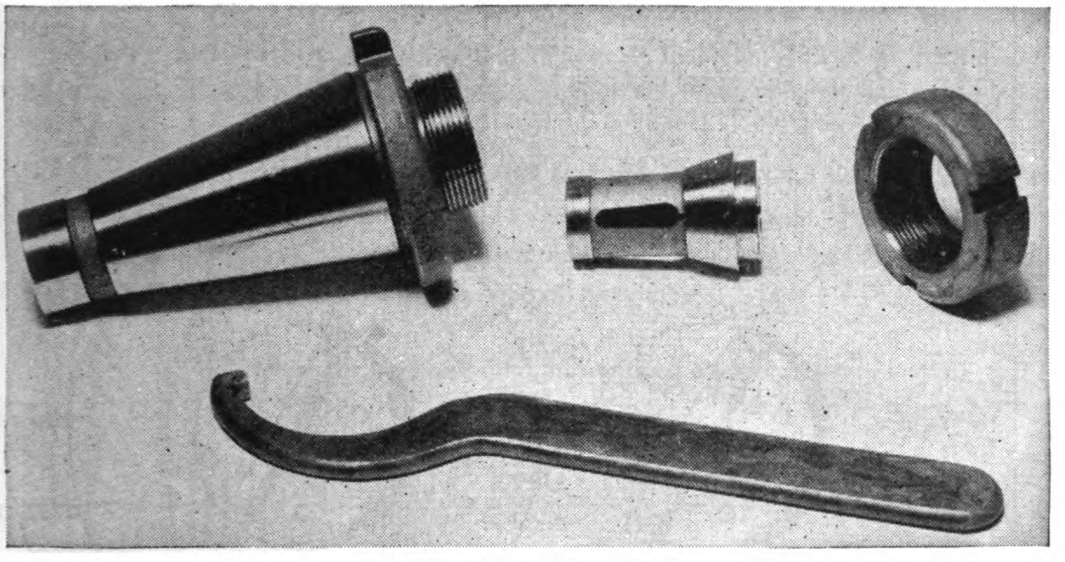


FIGURE 50.—Spring chucks.

a tapered seat. Straight shank cutters may be held in spring chucks or in cutter adapters of the type illustrated in figure 48③. Adapters for this purpose usually have some means, such as a set screw, to assist in driving the cutter.

c. For more positive drive and easier removal, large face milling cutters are generally mounted directly upon the milling machine spindle.

(1) The method illustrated in figure 51 makes use of a flanged spindle end of a definite size, so that face milling cutters may be used on all sizes of milling machines. Hardened keys are arranged radially on the end of this flanged portion. The back of the cutter is counterbored to fit the flanged end of the spindle, providing a positive method of centering. Keyways are milled in the back of the cutter to fit over the keys on the end of the spindle. The cutter

is held to the flanged end of the spindle by means of four cap screws that are screwed into the milling machine spindle end.

(2) Face milling cutters may also be held on cutter arbors of the type illustrated in figure 47②.

10. Speeds, feeds, and cutting lubricants.—Heat generated by friction between the cutter and the work may be regulated by the use of proper speed, feed, and cutting lubricant. This is extremely important as the cutter will be dulled or even rendered useless by overheating.

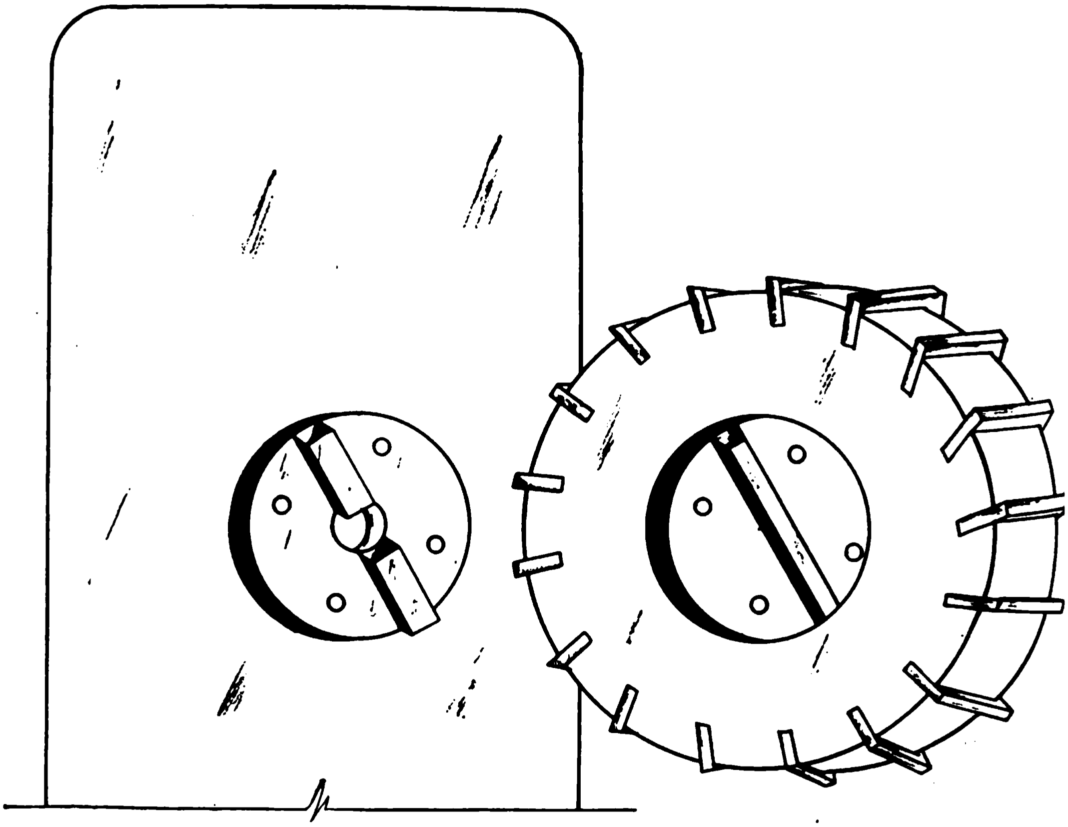


FIGURE 51.—Face milling cutter mounting.

a. Varying conditions encountered in milling machine work make it impossible to have fixed rules for cutting speeds. Generally speaking, a cutting speed should be selected that will give the best compromise between the maximum production and the longest life of the cutter. Several factors determine the cutting speed in any operation. These factors are—

(1) *Hardness of the material being cut.*—The harder and tougher the metal, the slower should be the cutting speed, since the frictional heat is greater with harder materials.

(2) *Depth of cut and type of finish being produced.*—These factors must be considered, as the amount of frictional heat generated is directly proportional to the amount of material being removed. Finishing cuts may often be made at a speed 40 to 80 percent higher than that used in roughing.

(3) *Cutter material.*—High speed cutters due to their heat resistant properties may be operated at from 50 to 100 percent faster than carbon steel cutters.

(4) *Type of cutter teeth.*—Cutters having undercut teeth cut more freely than those having a radial face; hence they may be run at higher speeds.

(5) *Sharpness of the cutter.*—A sharp cutter may be operated at a much higher speed than a dull one.

(6) *Lubrication.*—A plentiful supply of cutting lubricant on most materials will assist in cooling the cutter so that it will not overheat at relatively high speeds.

b. The approximate values, given in table I, may be used as a guide in selecting the proper speed. If the operator finds that either the machine, the cutter, or the work cannot be suitably operated at these speeds, immediate readjustment should be made.

TABLE I.—*Surface cutting speed for carbon and high speed steel cutters*

Material	Carbon steel cutters (ft. per min.)	High speed steel cutters (ft. per min.)
Aluminum	375 to 600	400 to 1,000
Brass	80 to 100	150 to 200
Cast iron	40 to 60	80 to 100
Low carbon steel	30 to 40	80 to 100
Annealed tool steel	20 to 30	60 to 80

(1) By referring to table II the cutter revolutions per minute may be determined for cutters varying in diameter from 1/4 to 8 inches. For example, when cutting with a 1-inch cutter and a surface speed of 80 feet per minute is required, the cutter revolutions per minute will be 306.

TABLE II.—*Cutter speeds in revolutions per minute*

Diameter of cutter (inches)	Surface speed (feet per minute)																
	25	30	35	40	50	55	60	70	75	80	90	100	120	140	160	180	200
	Cutter revolutions per minute																
1/4	382	458	535	611	764	851	917	1,070	1,147	1,222	1,376	1,528	1,834	2,139	2,445	2,750	3,056
5/16	306	367	428	489	611	672	733	856	917	978	1,100	1,222	1,466	1,711	1,955	2,200	2,444
3/8	255	306	357	408	509	560	611	713	764	815	916	1,018	1,222	1,425	1,629	1,832	2,036
7/16	218	262	306	349	437	481	524	611	656	699	786	874	1,049	1,224	1,398	1,573	1,748
1/2	191	229	268	306	382	420	459	535	573	611	688	764	917	1,070	1,222	1,375	1,528
5/8	153	184	214	245	306	337	367	428	459	489	552	612	736	857	979	1,102	1,224
3/4	127	153	178	203	254	279	306	357	381	408	458	508	610	711	813	914	1,016
7/8	109	131	153	175	219	241	262	306	329	349	392	438	526	613	701	788	876
1	95.5	115	134	153	191	210	229	267	287	306	344	382	458	535	611	688	764
1 1/4	76.3	91.8	107	123	153	168	183	214	230	245	274	306	367	428	490	551	612
1 1/2	63.7	76.3	89.2	102	127	140	153	178	191	204	230	254	305	356	406	457	508
1 3/4	54.5	65.5	76.4	87.3	109	120	131	153	164	175	196	218	262	305	349	392	436
2	47.8	57.3	66.9	76.4	95.5	105	115	134	143	153	172	191	229	267	306	344	382
2 1/2	38.2	45.8	53.5	61.2	76.3	84.2	91.7	107	114	122	138	153	184	213	245	275	306
3	31.8	38.2	44.6	51	63.7	69.9	76.4	89.1	95.3	102	114	127	152	178	203	228	254
3 1/2	27.3	32.7	38.2	43.6	54.5	60	65.5	76.4	81.8	87.4	98.1	109	131	153	174	196	218
4	23.9	28.7	33.4	38.2	47.8	52.6	57.3	66.9	71.7	76.4	86	95.6	115	134	153	172	191
5	19.1	22.9	26.7	30.6	38.2	42	45.9	53.5	57.3	61.1	68.8	76.4	91.7	107	122	138	153
6	15.9	19.1	22.3	25.5	31.8	35	38.2	44.6	47.7	51.0	57.2	63.6	76.3	89	102	114	127
7	13.6	16.4	19.1	21.8	27.3	30	32.7	38.2	41	43.7	49.1	54.6	65.5	76.4	87.4	98.3	109
8	11.9	14.3	16.7	19.1	23.9	26.3	28.7	33.4	35.9	38.2	43	47.8	57.4	66.9	76.5	86	95.6

(2) Should no table of values be available, the proper revolutions per minute may be determined by means of the following formula:

$$RPM = \frac{FPM}{0.2618 \times D}$$

Where:

RPM=revolutions per minute of the cutter.

FPM=required surface speed in feet per minute (table I).

D=diameter of cutter in inches.

c. The rate of feed, or the speed at which the work passes the cutter, determines the time required for cutting a job. In selecting the feed, there are several factors which should be considered. These factors are discussed below:

(1) Forces are exerted against the work, the cutter and their holding devices during the cutting process. The force exerted varies directly with the amount of metal removed and can be regulated by the feed and depth of cut. Therefore, the correct amount of feed and depth of cut are interrelated, and in turn are dependent upon the rigidity and power of the machine. Machines are limited by the power they can develop to turn the cutter, and the amount of vibration they can resist when using coarse feeds and deep cuts.

(2) The feed and depth of cut also depend upon the type of cutter being used. For example, deep cuts or coarse feeds should not be attempted when using a small diameter end mill, as such an attempt would spring or break the cutter. Coarse cutters with strong cutting teeth can be fed at a faster rate of feed because the chips may be washed out more easily by the cutting lubricant.

(3) Coarse feeds and deep cuts should not be used on a frail piece of work or on work mounted in such a way that its holding device is not able to prevent springing or bending.

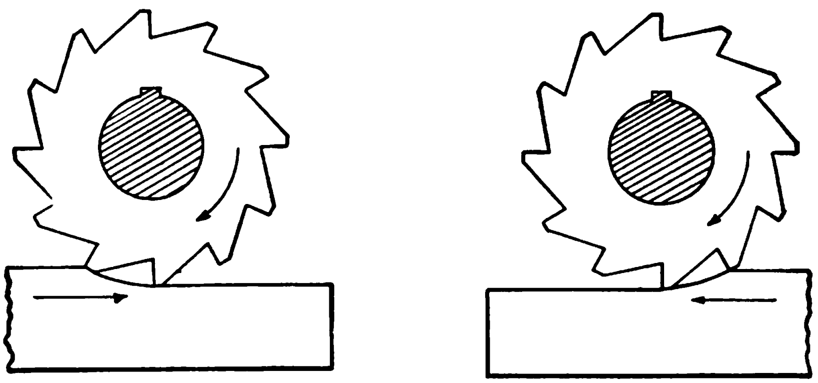
(4) The degree of finish desired regulates the amount of feed. When a coarse feed is used the metal is removed more rapidly but the appearance and the accuracy of the surface being cut may not reach the standard desired for the finished product. Because of this fact, finer feeds and increased speeds are used for finer, more accurate finishes, while for roughing it is good practice to use a comparatively low speed and a heavy feed. More mistakes are made on the side of overspeeding than on overfeeding. Overspeeding may be detected by the occurrence of a squeaking, scraping sound. If vibration (referred to as "chattering") occurs in the milling machine during the cutting process, the speed should be reduced and the feed increased. Too much cutter clearance, poorly supported work, or a machine gear that is badly worn are common causes of "chattering."

d. The feed of the milling machine may be designated either in "inches per minute" or "thousandths of an inch per revolution of the spindle."

(1) The "inches per minute" system is used in the newer machines, in which feed and spindle speed work independently of each other. Good finishes may usually be obtained with a feed of 4 to 6 inches per minute, while using a high speed cutter on steel. A good cutting compound should be employed in either case.

(2) The "thousandths of an inch per revolution of spindle" system is used on the cone drive machines on which speed and feed are interdependent, and a change in speed causes a similar change in feed.

e. In selecting the direction of cutter rotation and the direction of table travel, the usual practice is to cause the cutter to revolve against the advance of the table, as shown in figure 52①. Exceptions to this general practice are made in the milling of deep slots or in cutting off thin stock with a metal slitting cutter. In these exceptions, it is better to move the work with the cutter, as shown in figure 52②,



① Opposite work movement (up method). ② With work movement (down method).

FIGURE 52.—Direction of cutter rotation.

since there is less chance of producing crooked slots due to the cutter being crowded to one side. When the work is moving with the cutter, care must be taken to eliminate any looseness or lost motion in the table by setting the table gibs snugly. Failure to eliminate looseness, allows the cutter teeth to draw the work in, which may ruin both the work and the cutter.

f. Cutting lubricants.—The major advantage of a cutting lubricant is that it reduces frictional heat, thereby giving longer life to the cutting edge. The lubricant also serves to lubricate the cutter face and to flush away the chips, consequently reducing the possibility of marring the finish.

(1) Commercial cutting compounds are widely used because of their effectiveness and the ease with which they may be mixed. If such a compound is not available, a good substitute may be made by thoroughly mixing one ounce of sal soda and one quart of lard oil to one gallon of water. This emulsion is suitable for the machining of most metals. In the machining of aluminum, kerosene should be used as a cutting lubricant, while cast iron should be machined dry although a blast of compressed air may be used to cool the work and the cutter.

(2) The lubricant should be directed, by means of the coolant drip can or pump system, to the point where the cutter strikes the work. Regardless of which method is used, the coolant should be allowed to flow freely on the work and cutter.

SECTION III

HOLDING AND INDEXING WORK

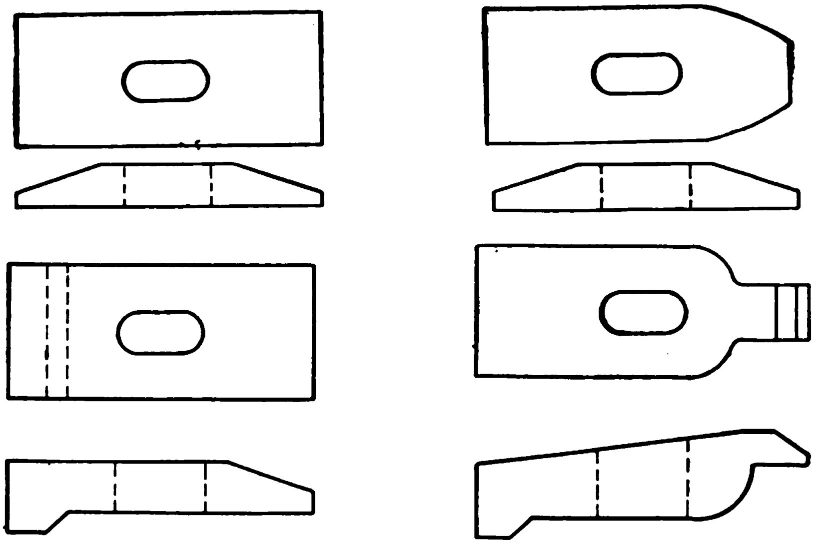
11. General.—*a.* An efficient and positive method of holding work on the milling machine is most important if the machine tool is to be used to its best advantage. Regardless of the method used in holding, there are certain factors that should be observed in every case. The work must not be sprung in clamping; it must be secured to prevent it from springing or moving away from the cutter and it must be so alined that it may be correctly machined.

b. Milling machine tables are provided with several T-slots which are used either for clamping and locating the work itself or for mounting the various holding devices and attachments. These T-slots extend the length of the table and are parallel to its line of travel. Most milling machine attachments, such as vises and index heads, have keys or tongues on the underside of their bases so that they may be located correctly in relation to the T-slots.

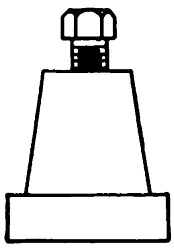
12. Methods of holding work.—There are various methods of holding work, each being dependent upon the type of work and the operation to be performed. The commonly used methods are described in the following paragraphs:

a. Clamping to the table.—When clamping work to the milling machine table, the table and work should be free from dirt and burs.

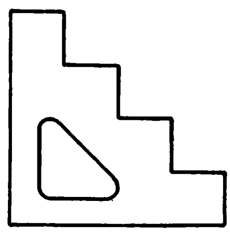
Work having smooth machined surfaces may be clamped directly to the table, provided the cutter does not come in contact with the table surface during the machining operation. When clamping work with unfinished surfaces in this way, the table face should be protected by pieces of soft metal. Clamps should be placed squarely across the



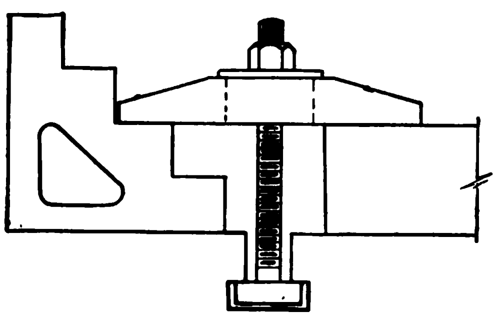
① ② ③ and ④ Clamps.



⑤ Jack.



⑥ Step block.



⑦ Typical application of clamp.

FIGURE 53.—Clamping devices.

work in order to give a full bearing surface. These clamps are held by bolts inserted in the T-slots of the table. Clamping bolts should be placed as near the work as possible so that full advantage of the fulcrum principle may be obtained. When it is necessary to place a clamp on an overhanging part, a support should be provided between the overhang and the table to prevent springing or possible breakage. A stop should be placed at the end of the work where it will receive the thrust of the cutter when heavy cuts are being

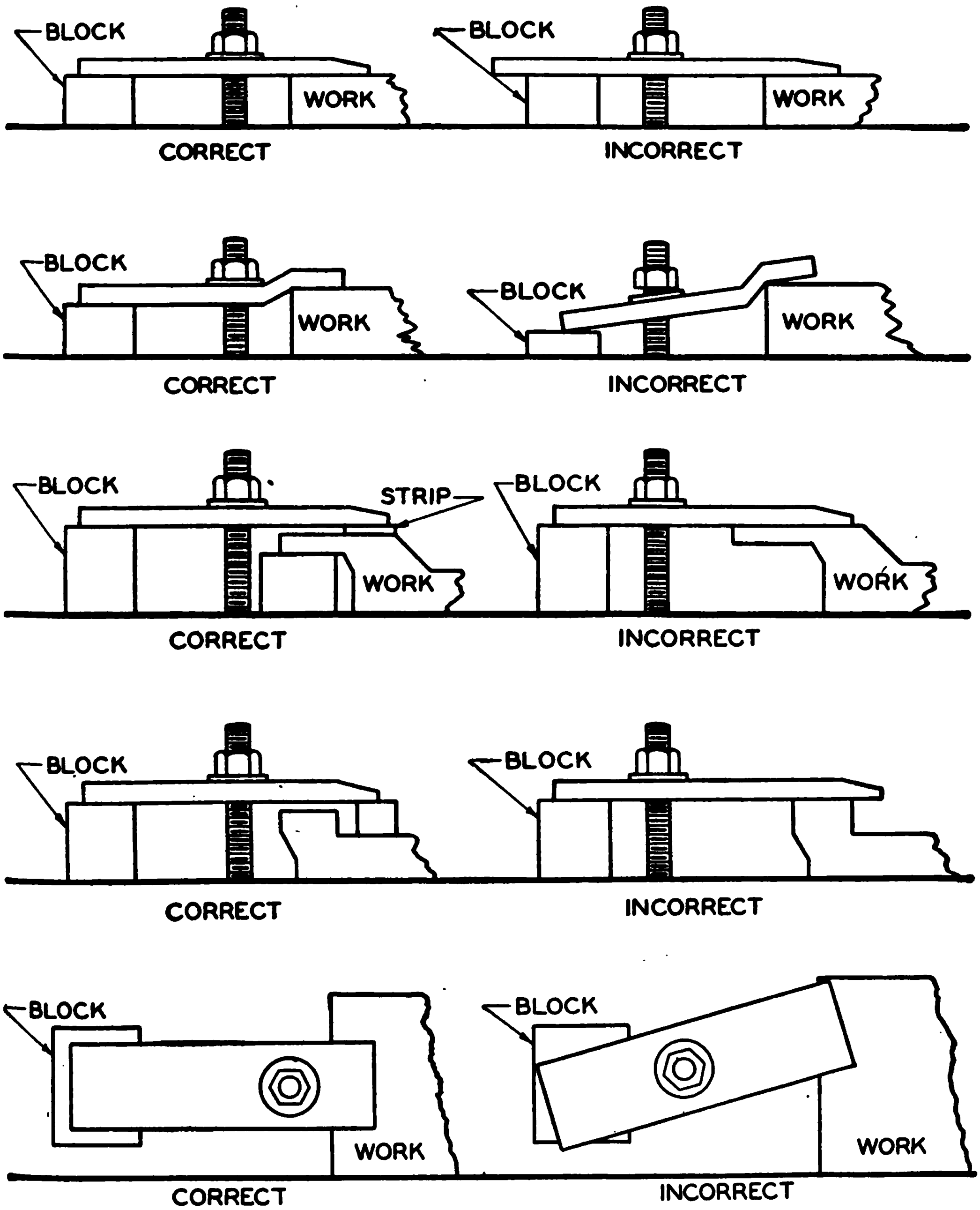


FIGURE 54.—Correct and incorrect clamping procedure.

taken. Figure 53 illustrates the various types of clamps in general use while figure 54 shows proper methods of application.

b. Clamping work to the angle plate.—By clamping work to the angle plate, surfaces may be machined parallel, perpendicular, or at an angle to a given surface. When using this method of holding work, precautions should be taken similar to those recommended for clamping directly to the table. Angle plates may be of either the adjustable or the nonadjustable type and are generally held in alinement by means of keys or tongues that fit into the table T-slots.

(1) The adjustable type angle plate (fig. 55) has a hinged member upon which the work is clamped. This member may be adjusted and locked at various angles with respect to the base.

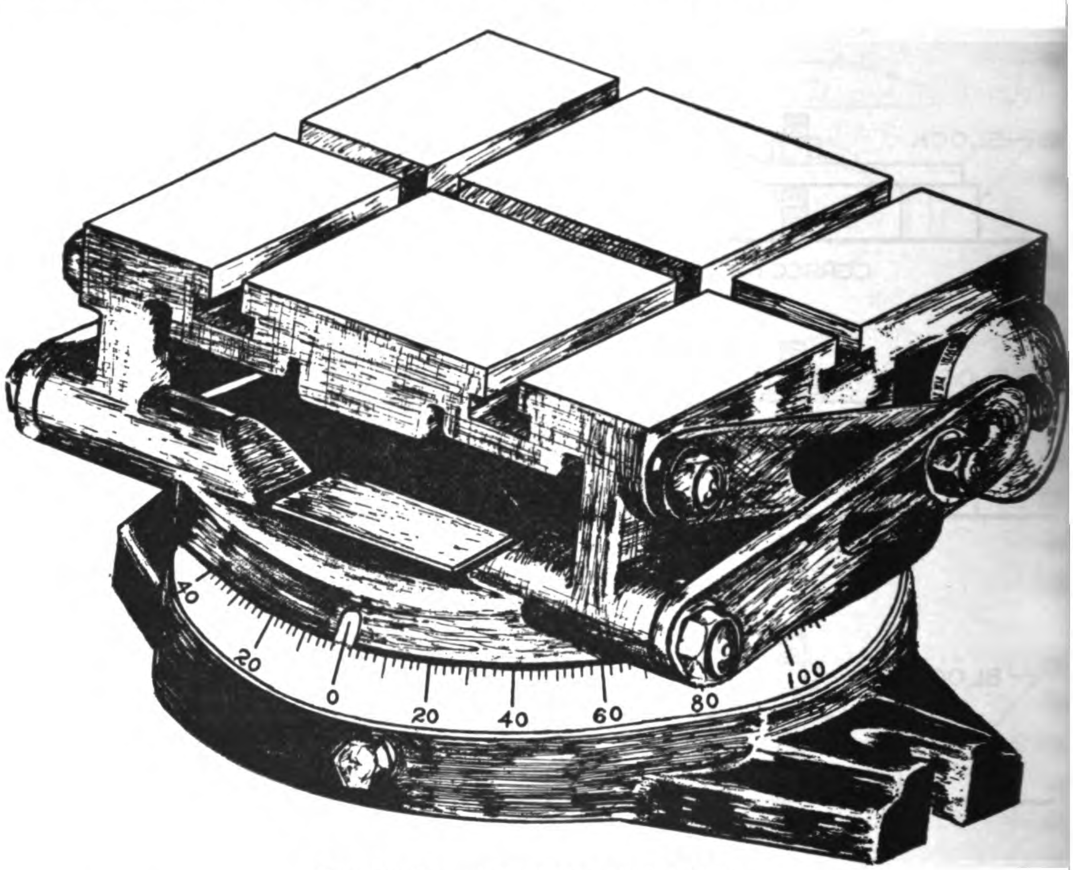


FIGURE 55.—Adjustable angle plate.

(2) Standard nonadjustable angle plates usually have two outer surfaces machined at 90° to each other. A typical set-up involving its use is illustrated in figure 86.

c. Clamping work in fixtures.—Fixtures are generally used in production work where a number of similar pieces are to be machined. The design of the fixture is dependent upon the shape of the work and the operations to be performed. Fixtures are always constructed to secure maximum clamping surfaces and are built to use a minimum number of clamps or bolts in order to reduce the time required for setting up. Fixtures should always be provided with keys to assure positive alinement with the table T-slots.

d. Holding work between centers.—The index centers are used to support work which is centered on both ends. When the work has been previously reamed or bored, it may be pressed upon a mandrel and then mounted between the centers as shown in figure 101.

(1) Two types of mandrels may be used for mounting work between centers. The common or lathe mandrel is satisfactory for many operations, while one having a shank tapered to fit into the index head spindle is preferred in certain cases. In this latter type, the outer end of the mandrel is supported by the footstock center in the regular manner.

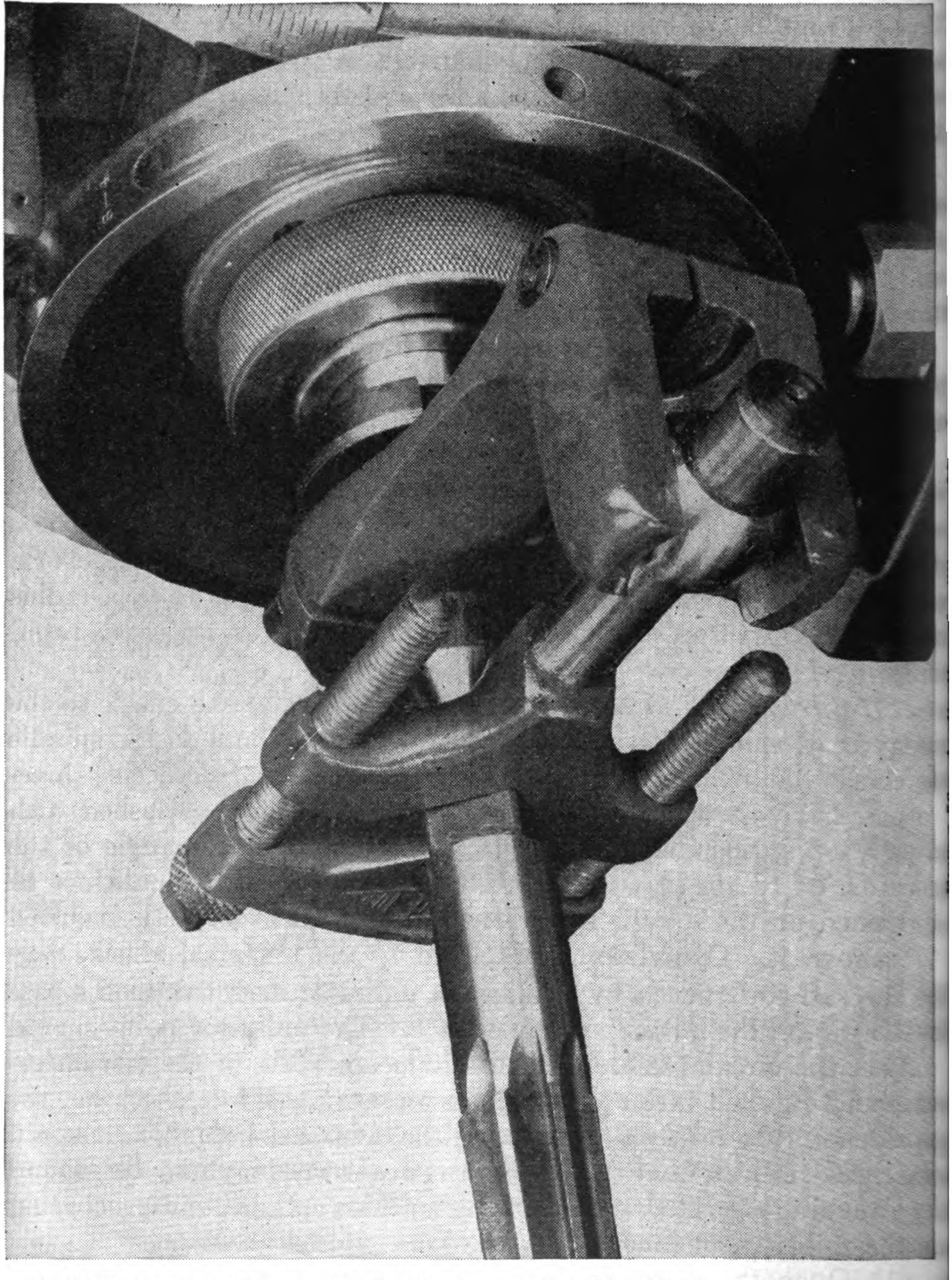
(2) The center rest, shown at (12) in figure 1, prevents springing and is used to support long slender work held between centers or work that extends some distance from the chuck.

(3) Work mounted upon centers is driven by means of a dog as shown in figure 79. The bent tail of this dog should be fastened between the set screws provided in the driving center clamp, in such a manner as to avoid backlash and prevent springing of the mandrel. When milling certain types of work, a milling machine dog (fig. 56) may be utilized to advantage. The tail of this dog is held in a flexible ball joint which eliminates shake or spring of the dog or the work. The flexible ball joint allows the tail of the dog to move in a radius along the axis of the work, making it particularly useful in the rapid milling of tapered work.

e. Holding work in the chuck.—Before screwing the chuck to the index head spindle, it should be cleaned and any burs on the spindle or chuck removed. Burs may be removed with a smooth cut, three-cornered file or scraper, while cleaning should be accomplished with a piece of spring-steel wire, bent and formed to fit the angle of the threads, or by the use of compressed air. The chuck should not be tightened on the spindle so tightly that a wrench or bar is required to remove it. Cylindrical work, held in the universal chuck, may be checked for trueness by using a test indicator mounted upon a base resting upon the milling machine table. The indicator point should contact the circumference of small diameter work, or the circumference and exposed face of large diameter work. While checking, the work should be revolved by rotating the index head spindle. Should the check indicate that the chuck jaws are worn, they may be ground by attaching the chuck to the milling machine spindle, and proceeding in the following manner:

(1) Open the chuck jaws until they contact a steel ring with a concentric inner diameter of a size that will allow a jaw opening of approximately 1 inch.

(2) Clamp a small, tool post grinder to the milling machine table, and with both the chuck and grinding wheel revolving, grind the chuck jaws by moving the milling machine table transversely.



f. Holding work directly in the index head.—Work that is mounted on taper shank arbors or pieces having a suitable taper may be held directly in the index head spindle as shown in figure 108.

g. Holding work in a collet.—Cylindrical work of small diameter, uch as screws, may be held by means of the spring chuck and collet s shown in figure 29. The spring chuck should be inserted into the ndex head spindle and the proper size collet placed in the chuck. 'he work may then be mounted in the collet and the cap nut tightned, forcing the collet jaws against the tapered seat and clamping hem on the work. The advantage of using the collet lies in the act that the work may be clamped rapidly and accurately.

h. Holding work in the vise.—As previously mentioned, three types f vises are manufactured in various sizes for holding milling mahine work. These vises have locating keys or tongues on the under ide of the base so that they may be located correctly in relation to he T-slots on the milling machine table.

(1) The plain vise (fig. 8) may be fastened to the milling machine able and located either parallel or perpendicular to the arbor by neans of the keys.

(2) The swivel vise (fig. 9) is fitted into a graduated circular base vhich is fastened to the milling machine table and located by means of keys placed in the T-slots. By loosening the bolts which clamp he vise to its graduated base, the vise may be moved to hold work it any angle in a horizontal plane. To set a swivel vise accuately with the machine spindle, a test indicator should be clamped o the machine arbor, and a check made to determine the setting by noving either the transverse or the longitudinal feeds, depending ipon the position of the vise jaws. Any deviation as shown by the est indicator should be corrected by swiveling the vise on its base.

(3) The universal vise (fig. 10) is constructed in such a way as o allow it to be set at any angle, either horizontally or vertically, o the axis of the milling machine spindle. Due to the flexibility of this vise, it is not adaptable for heavy milling.

(4) When rough work or work with unfinished surfaces is to be held in a vise, a piece of protecting material should be placed between the vise and the work to eliminate any marring of the jaws.

(5) When it is necessary to raise work above the vise jaws, parallels of the same size and of the proper height should be used. These parallels should only be high enough to allow the required cut as excessive raising reduces the holding ability of the jaws. When holding work on parallels, a soft hammer should be used to tap the top surface of the work, after the vise jaws have been tightened. This tapping should be continued until the parallels cannot be moved by hand and after once being set, additional tightening of the vise should not be attempted, as such tightening has a tendency to raise the

work off the parallels. Correct selection of parallels is illustrated in figure 57.

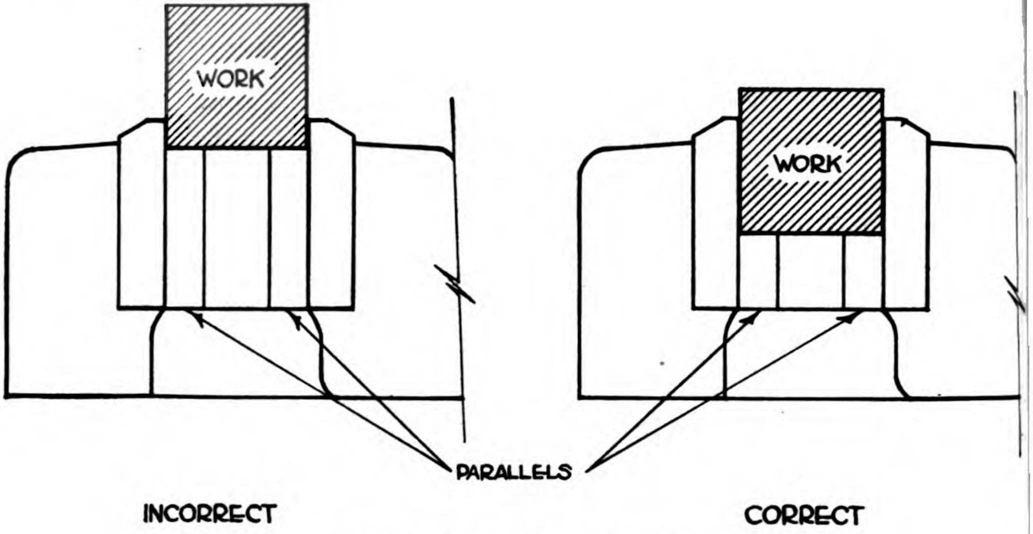
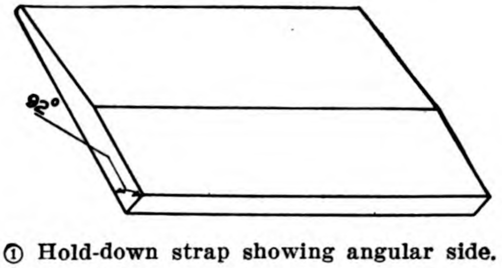
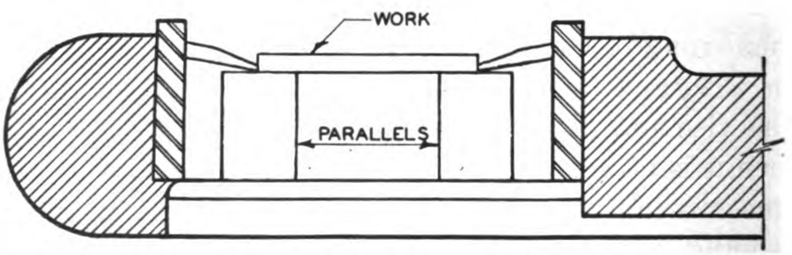


FIGURE 57.—Selection of parallels.

(6) If the work is so thin that it is impossible to let it extend over the top of the vise, hold-down straps, such as those illustrated in figure 58, are generally used. These straps are hardened pieces of steel, having



① Hold-down strap showing angular side.

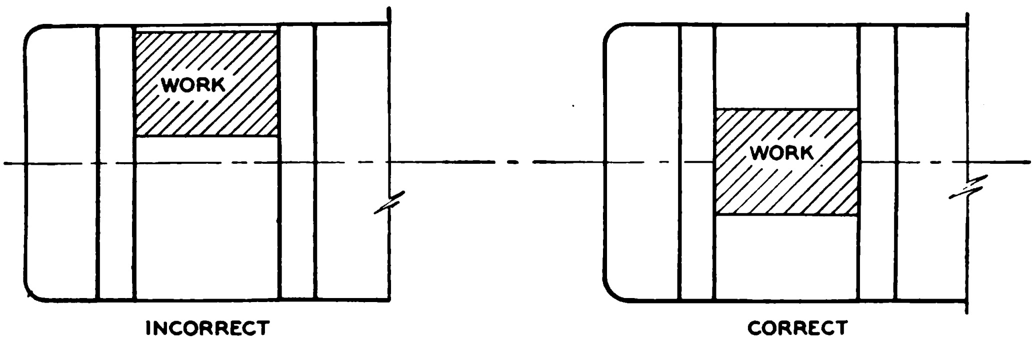


② Application of hold-downs.

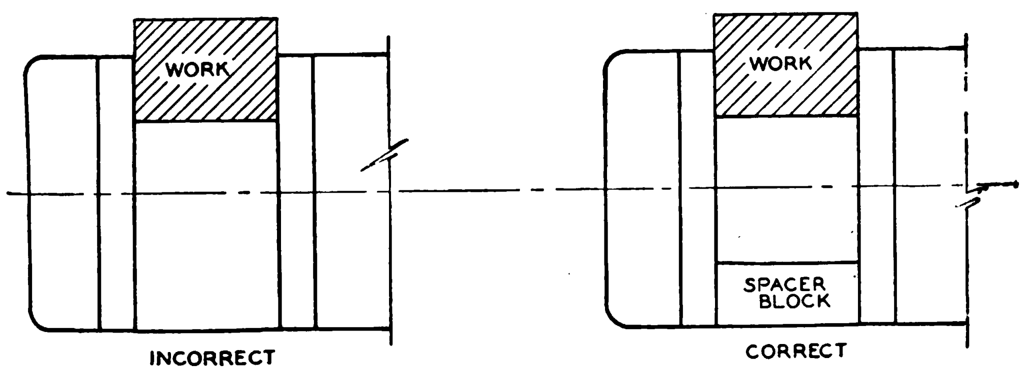
FIGURE 58.—Hold-downs.

one vertical side tapered to form an angle of about 92°, with the bottom side and the other vertical side tapered to a narrow edge. By means of these tapered surfaces, the work is forced downward on to the parallels, holding them firmly and leaving the top surface of the work fully exposed to the cutting tool.

(7) Whenever possible, work should be clamped in the center of the vise jaws; however, when necessary to mill a short piece of work which must be held at the end of the vise, a spacing block of the same thickness as the work should be placed at the opposite end of the jaws. This will avoid strain on the movable jaw and prevent the work from slipping. Figure 59 illustrates the correct method of holding work in this manner.



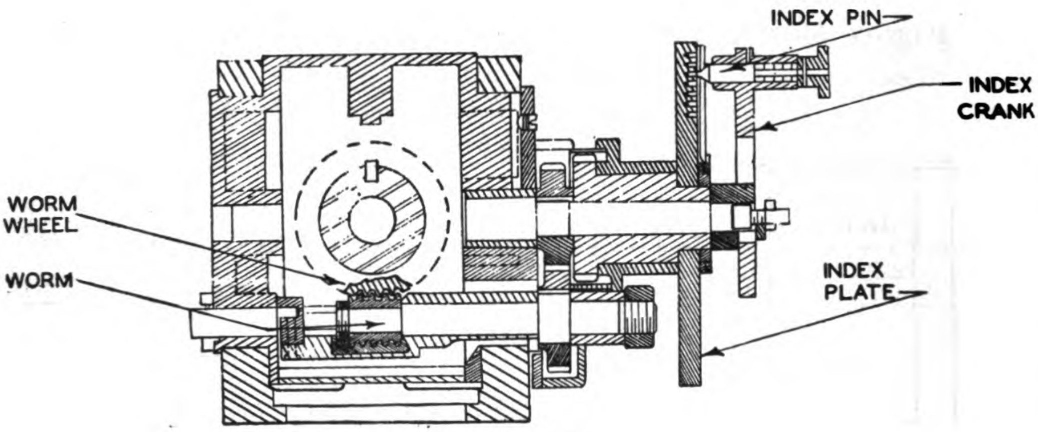
① Centering work in the vise jaws.



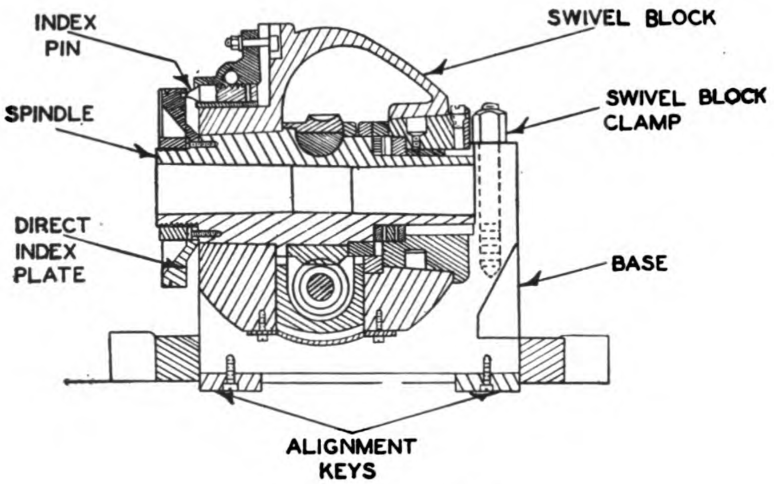
② Use of spaced block for locating work at end of vise.

FIGURE 59.—Clamping work in the vise.

13. Index head.—The index or dividing head is used primarily to evenly divide or space work, such as required in the cutting of tooth spaces on gears and the milling of grooves in reamers and taps. The index head is supported on a base plate casting that is provided with keys on its under side for alinement on the milling machine table. As shown in figure 60, two large bearings are provided on the sides of the base plate, into which the swivel block is fitted. These bearings allow the swivel block to be set at any desired angle from 10° below the horizontal to 5° beyond the perpendicular. Graduations on the side of the head indicate the angular position in half degrees. A clamping device is incorporated in the base plate by which the swivel block may be clamped at any angular position within its range. The swivel block contains the headstock spindle that passes through the block and is held in place by means of a thrust nut on one end. The opposite end, called the work end, is threaded or flanged and contains a tapered hole.



① Side view.



② Front view.

FIGURE 60.—Index head.

The tapered hole provides a means for holding taper shank tools, while the threaded or flanged portion is used to hold chucks. Direct index plates are generally mounted just back of the work end. The spindle may be rotated by means of the index crank, by direct indexing, or by the table feed screw; the latter method being used only for helical milling operations.

14. Indexing.—Indexing may be accomplished by means of the plain, direct, compound or differential methods. Of these methods, the plain and direct are the most commonly used, the compound and differential being less practicable. The compound method which was used to a considerable extent in the past is becoming obsolete, due to the chance for errors and the fact that exact results cannot be obtained. Differential indexing, although accurate, is not widely used, due to the lengthy set-up required. It does, however, become necessary in certain instances which are beyond the range of plain and direct indexing. Differential indexing should not be attempted without reference to the manufacturer's handbook as the various manufacturers have different systems of accomplishing the operation.

a. Direct indexing, sometimes called rapid indexing, makes use of the direct index plate which is mounted just back of the work end of the index head spindle. A direct index plate has a number of equally spaced holes near the periphery, into which the index pin may be inserted as shown in figure 60②. With the index pin out of contact with the direct index plate, the spindle may be disengaged and indexing accomplished by turning the spindle by hand. To divide work into two equal parts, the index pin should be disengaged and the plate and spindle revolved until 11 holes in a 24-hole circle have passed the index pin. The index pin is then inserted into the 12th hole in the plate to hold the spindle in the proper position. During heavy cutting operations, the spindle should be clamped by means of the clamp screw to relieve strain on the index pin.

b. Plain indexing, accomplished by using the universal index head, is governed by the number of times the index crank must be turned to cause the work to make one revolution. Charts specifying the required number of turns or fractions of a turn and giving the proper index plate for various divisions, are furnished by index head manufacturers. However, when these charts are not available, the required number of turns and parts of turns may be determined by simple calculation. Figure 61 illustrates the mechanism contained in the swivel block of the index head. The main spindle is attached to a worm wheel which is driven by a worm mounted on a shaft. On the outer end of this shaft, an index crank is located for revolving the spindle when doing plain indexing. The worm is single threaded and the worm wheel has 40 teeth, so that 40 turns of the index crank are necessary to turn the spindle one complete revolution. Therefore, the number of turns of the index crank required to index a fractional part of a revolution is determined by dividing 40 by the number of divisions desired. For example, if it is required to make 40 divisions on a piece of work, 40 would be divided by 40, indicating that one complete turn of the index crank is required for each division. If 10 divisions were required, 40 would be divided by 10 and 4 complete turns of the index crank would be required for each division. Index plates (fig. 62) are used to assist in making the division when the quotient of the ratio of the index head and the division desired results in a fraction, making it necessary to give the crank a part of a revolution in indexing. These plates are circular disks, having six or more concentric circles of equally spaced holes; the number of holes differing in each circle. The plate is fastened to the index head between the swivel block and the crank, and the crank is positioned by means of a radial adjustment so that the index pin, which it houses,

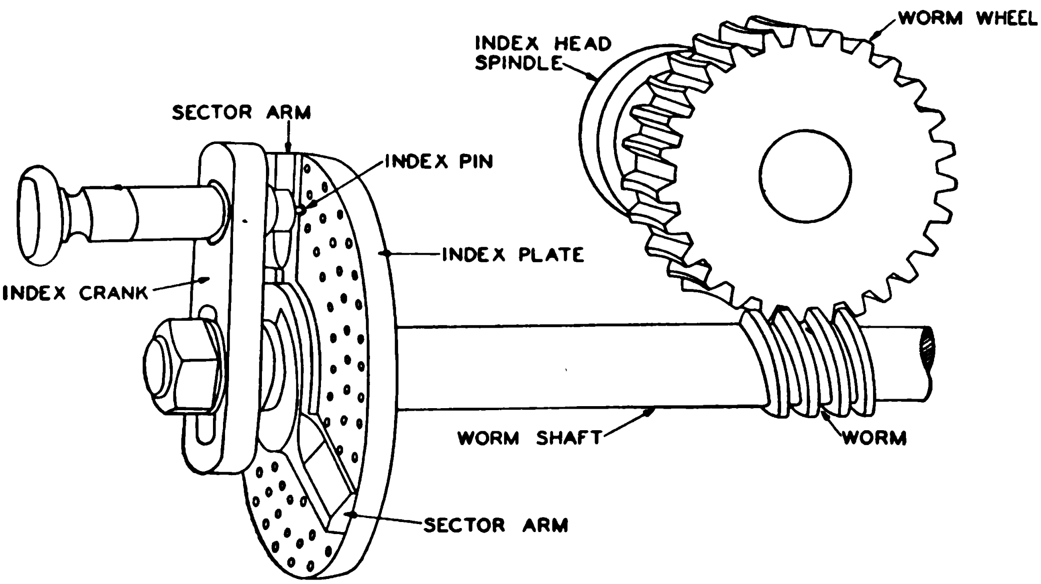


FIGURE 61.—Index head mechanism.

can be used in any of the circles of holes on the plate. The numerator of the fraction, determined by dividing 40 by the number of divisions required, represents the number of holes in a circle of holes that the index crank should be moved for each desired division. The denominator of this fraction represents the number of holes in the correct circle of holes which should be selected on the index plate. For example, the calculation for determining 800 divisions when an index plate with 20 holes is available, is as follows:

$$\frac{40}{800}=\frac{1}{20} \text{ or 1 hole in a 20-hole circle.}$$

(1) When the fraction is such that none of the available index plates contain the number of holes represented by the denominator

a fraction should be established, the denominator of which represents the number of holes for which an index plate is available. To obtain this fraction, both the numerator and the denominator must be raised by a common multiplier. For example, the calculation for determining 9 divisions when an index plate having a 27-hole circle is available, is as follows:

$$\frac{40}{9} \times \frac{3}{3} = \frac{120}{27} = 4\frac{12}{27}$$ or 4 complete turns and 12 holes in a 27-hole circle.

(2) On the other hand, if the denominator of the fraction is larger than the number of holes that are available in an index plate, both the numerator and the denominator should be divided by a common divisor that will give a fraction in which the denominator represents the number of holes for which an index plate is available. For example, the calculation for determining 76 divisions when an index plate having a 19-hole circle is available, is as follows:

$$\frac{40}{76} \div \frac{4}{4} = \frac{10}{19}$$ or 10 holes in a 19-hole circle.

(3) If, when reducing the fraction, as discussed in the foregoing paragraph, the denominator becomes so small that no available index plate contains the number of holes represented by the denominator, the fraction should be raised to an available number. For example, the calculation for determining 52 divisions when an index plate with a 39-hole circle is available, is as follows:

$$\frac{40}{52} \div \frac{4}{4} = \frac{10}{13} \times \frac{3}{3} = \frac{30}{39}$$ or 30 holes in a 39-hole circle.

(4) When it is necessary to divide work into degrees or fractions of degrees by plain indexing, it should be remembered that 1 turn of the index crank will rotate a point on the circumference of the work $\frac{1}{40}$ of a revolution. Since there are 360° in a circle, one turn of the index crank would revolve the circumference of the work $\frac{1}{40}$ of 360° or 9°. Hence, when using the index plate and fractional parts of a turn, 2 holes in an 18-hole circle equals 1°, 1 hole in a 27-hole circle equals $\frac{1}{3}$°, 6 holes in a 54-hole circle equals 1°, 4 holes in a 54-hole circle equals $\frac{2}{3}$°, 3 holes in a 54-hole circle equals $\frac{1}{2}$°, and 2 holes in a 54-hole circle equals $\frac{1}{3}$°. To determine the number of turns and parts of a turn of the index crank for a desired number of degrees, the number of degrees should be divided by 9, and the quotient will represent the number of complete turns and fractions of a turn that the index crank should be rotated.

For example, the calculation for determining 15° when an index plate with a 54-hole circle is available, is as follows:

$$\frac{15}{9}=1\tfrac{6}{9}=1\frac{36}{54}$$

or 1 complete turn of the index crank and 36 holes in a 54-hole circle. The calculation for determining 13½° when an index plate with an 18-hole circle is available, is as follows:

$$\frac{13.5}{9}=1\frac{4.5}{9}=1\frac{9}{18}$$ or 1 complete turn and 9 holes in an 18-hole circle.

(5) When indexing angles given in minutes, where approximate divisions are acceptable, the movement of the index crank and the proper index plate may be determined by the following calculations: The number of minutes represented by 1 turn of the index crank can be determined by multiplying the number of degrees covered in 1 turn of the index crank by 60. Thus: $9\times60=540$; 540 is therefore the number of minutes represented by 1 turn of the index crank.

(*a*) The quotient of 540, divided by the number of minutes in the division desired, represents the number of holes in the index plate circle on which the index crank should be moved 1 hole to obtain the required division in minutes. As mentioned in the preceding discussion, this method of indexing can be used only for approximate angles since ordinarily the quotient will come out in mixed numbers or in numbers for which there are no index plates available. However, when the quotient is nearly equal to the number of holes in an available index plate, the nearest number of holes can be used and the error will be very small. For example, the calculation for 24 minutes would be as follows:

$$\frac{540}{24}=22.5$$

Since there is no 22.5-hole circle on the index plate, a 23-hole circle plate would be used.

(*b*) If the quotient is not approximately equal to an available circle of holes, it should be multiplied by any trial number which will give a product equal to the number of holes in one of the available index circles. The crank can then be moved the required number of holes to give the desired division. For example, the calculation for determining 54 minutes when an index plate having a 20-hole circle is available, is as follows:

$$\frac{540}{54}=\frac{10}{1}\times\frac{2}{2}=\frac{20}{2}$$ or 2 holes in a 20-hole circle index plate.

(6) The index head sector is used to expedite the proper movement of the index crank when fractional parts of a complete turn are to be made. The sector, as illustrated in figure 62, consists of two radial arms that may be spread apart when a set screw is loosened. To use the sector, the left hand arm is turned to bear on the left side of the index pin which is inserted into the first hole in the circle that is to be used. The set screw is then loosened and the right-hand arm of the sector is adjusted so that the correct number of holes will be

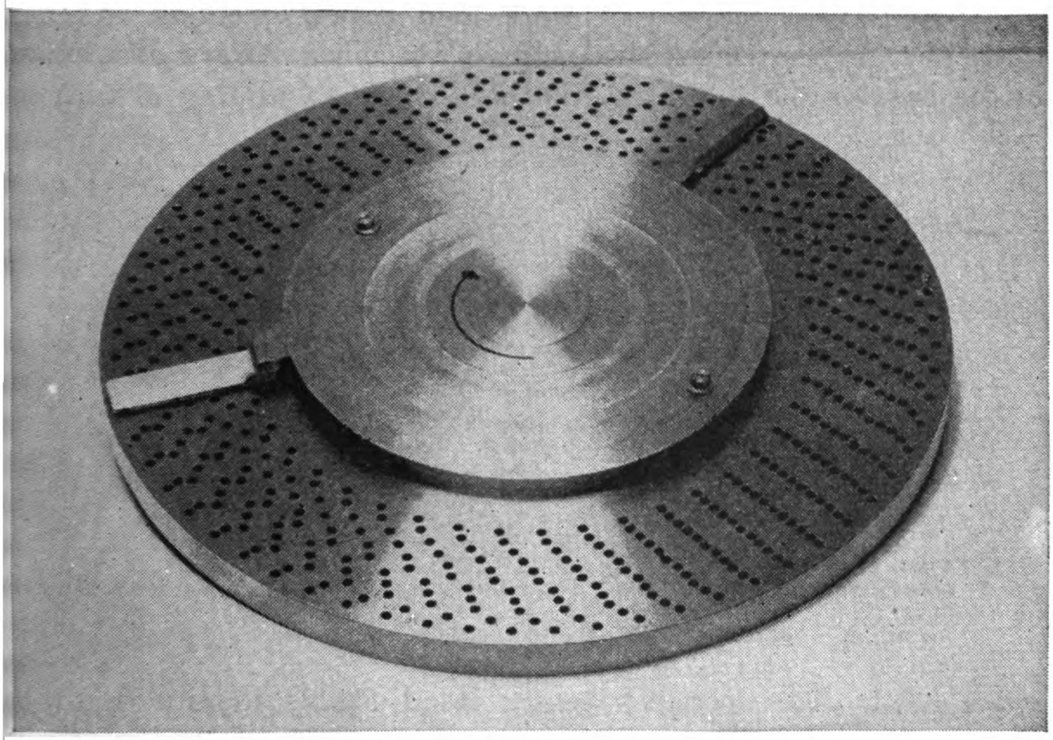


FIGURE 62.—Index plate and sector arm.

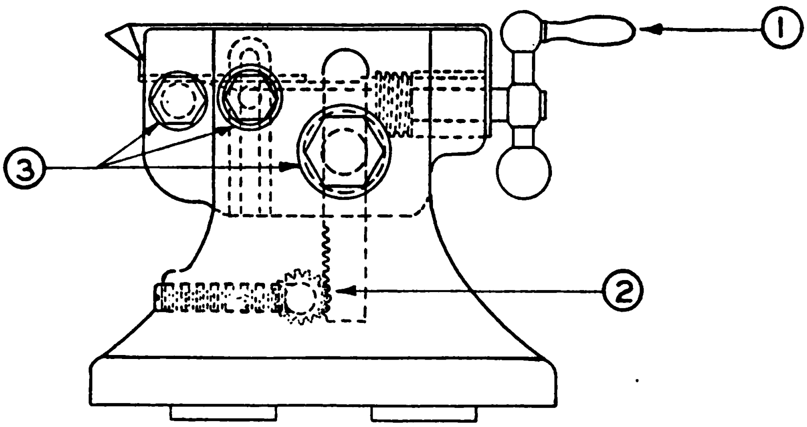
contained between the two arms. After making the adjustment, the set screw is locked to hold the arms in position. When setting the arms, the required number of holes is counted from the one in which the pin is inserted, considering this hole as zero. By subsequent use of the index sector, the counting of the holes after each division is eliminated. When using the index crank to revolve the spindle it is necessary that the spindle clamp screw be unlocked; however, before cutting work held in or on the index head, the spindle should again be locked to relieve the strain.

(7) The indexing that may be accomplished with standard plates, usually ranges as follows: all divisions up to and including 60, all

even divisions and miscellaneous uneven divisions up to and including 400. Special index plates may be obtained for divisions that cannot be made by using standard index plates. Index plates are removable and reversible and one or more are furnished as regular equipment with the index head.

(8) A wide range divider is manufactured for use with some types of universal index heads. The wide range divider consists of a small index plate and reduction gearing to give a ratio of 100 to 1. By the use of this attachment, divisions from 2 to 400,000 may be obtained.

15. Footstock.—*a.* The footstock, shown in figure 63, is used for supporting the outer end of work held between centers and long work held in the index head spindle or chuck. Keys are located in the base of the footstock for the purpose of alining it with the



1. Longitudinal adjusting crank. 2. Vertical adjusting screw. 3. Center clamps.

FIGURE 63.—Milling machine footstock.

index head. The footstock center is adjustable longitudinally by means of a hand crank. The center can also be moved vertically and set out of parallel with the base by the use of a movable block into which the center is fitted. The vertical and angular adjustment of the footstock center is to allow tapered work to be alined rapidly.

b. To accomplish accurate work, the footstock and dividing head centers must be concentric and in proper alinement.

(1) Centers that are worn or not concentric should be removed from the milling machine and ground concentrically to a 60° angle on the lathe or grinding machine.

(2) The alinement of the index head center and footstock center may be checked as follows:

(*a*) Clean the tapered hole of the index head spindle and insert a clean driving center.

(*b*) Place a test bar between the headstock and the tailstock centers.

(*c*) Clamp a dial test indicator to the milling machine arbor with the indicator contact point touching the top of the test bar.

(*d*) Move the table longitudinally and any undesirable deviation will be registered on the dial indicator. Adjustment may then be made by moving the footstock center vertically.

16. Helical milling.—*a. General.*—A helix may be defined as a regular curved path, such as is formed by winding a cord around the surface of a cylinder. Figure 64 represents the helix as being the hypotenuse of a right triangle which has been coiled about a cylinder. Helical parts, most commonly cut on the milling machine, include helical gears, milling cutters, twist drills, and helical

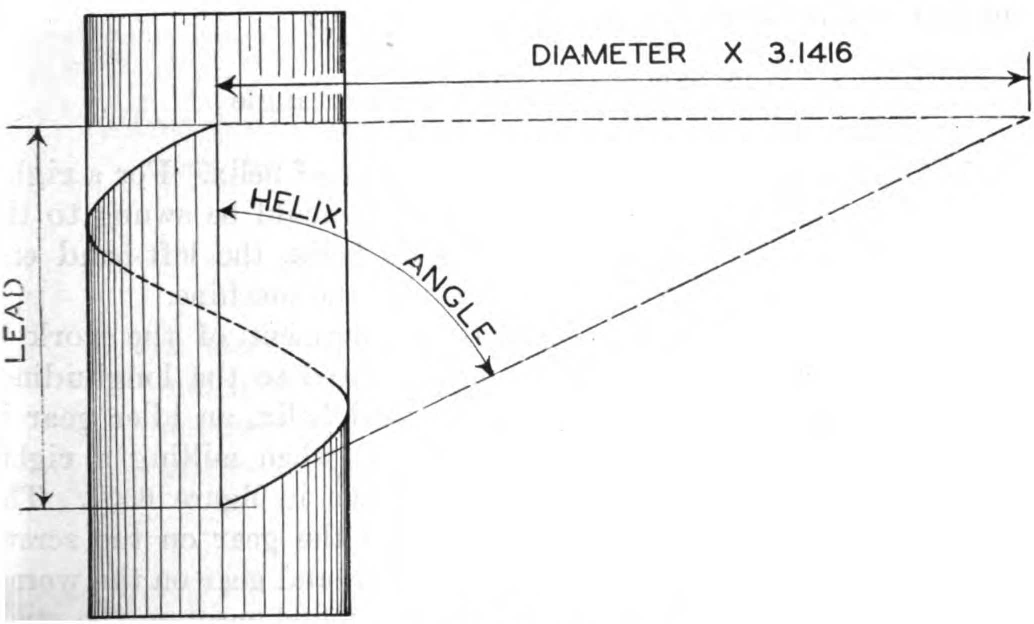


FIGURE 64.—Helix diagram.

cam grooves. When milling a helix, the universal index head is used to rotate the work at the proper rate of speed, while it is being fed against the cutter. A train of gears is placed between the table feed screw and the dividing head for the purpose of rotating the work the required amount, for a given longitudinal movement of the table. In machine shops, the term spiral is often used to mean helix; this usage is incorrect since a spiral is a curve having a constantly increasing radius similar to that of a watch spring.

b. The following is an explanation of the factors involved, and the calculations required in the cutting of a helix:

(1) The lead is the distance which the helix advances along the cylinder in one revolution measured parallel with its axis. A helix may have a lead much longer or much shorter than the piece being milled. For example, a reamer flute 6 inches in length, having a lead of 18 inches, would make only ⅓ of a complete revolution during the cut. When the angle of helix and the diameter are given, the lead may be found by multiplying the product of the diameter and pi by the cotangent of the angle. Thus: Diameter × 3.1416 × cotangent of angle = lead.

(2) The angle of helix is the angle between the hypotenuse of the triangle illustrated in figure 64 and the side representing the lead.

(*a*) When the lead and the diameter are given, the tangent of the angle of helix may be found by dividing the product of the diameter and pi by the lead, then converting to the helix angle by reference to trigonometrical tables. Thus:

$$\frac{\text{Diameter} \times 3.1416}{\text{lead}} = \text{tangent of angle}$$

(*b*) The work table must be set at the angle of helix. For a right-hand helix the right-hand end of the table should be swung to the rear of the machine, and for a left-hand helix, the left-hand end of the table should be swung to the rear of the machine.

(3) As previously mentioned, helical movement of the work is accomplished by having the index head geared to the longitudinal table feed screw. When milling a left-hand helix, an idler gear is necessary, as illustrated in figure 65①, and when milling a right-hand helix, the gears are arranged as shown in figure 65②. The four gears in this gear train are known as the gear on the screw, first gear on the stud, second gear on the stud, and gear on the worm. The driver gears are the screw gear and the first gear on the stud, while the driven gears are the second gear on the stud and the gear on the worm shaft.

(*a*) The leads that may be cut are governed directly by these gears, and therefore, by changing the gear combinations various leads may be cut. Manufacturers furnish charts giving information on the gears required for various leads on their milling machines. However, where these charts are not available, a formula for calculating the required gears may be used. This formula can be established as a ratio in which the lead of the machine is to the lead of the helix required as the product of the driving gears is to the product of the driven gears. Thus:

$$\frac{\text{lead of helix desired}}{\text{lead of machine}} = \frac{\text{product of driven gears}}{\text{product of driving gears}}$$

(*b*) To determine the lead of the machine, it must be remembered that the longitudinal feed screw of the table on all standard milling machines has 4 threads to the inch, and that 40 turns of the worm makes 1 turn of the index head spindle. Thus, if change gears of equal diameter are used, the table will move 10 inches longitudinally while the work is making 1 complete turn; therefore, the helix will have a lead of 10 inches and this 10-inch value is the lead of the machine.

(*c*) The following is an explanation of the calculations required for cutting a helix having a 12-inch lead:

1. A fraction should be established in which the numerator represents the lead of the helix desired and the denominator represents the lead of the machine. Thus:

$$\frac{12}{10} = \text{required fraction}$$

2. This fraction should be resolved into two factors to represent the two pairs of change gears. Thus:

$$\frac{12}{10} = \frac{3 \times 4}{2 \times 5}$$

3. The terms of both factors are then raised by a common multiplier to produce resulting numerators and denominators which will correspond with the number of teeth of the change gears furnished with the machine. Thus:

$$\frac{3 \times 12}{2 \times 12} = \frac{36}{24} \quad \text{and} \quad \frac{4 \times 8}{5 \times 8} = \frac{32}{40}$$

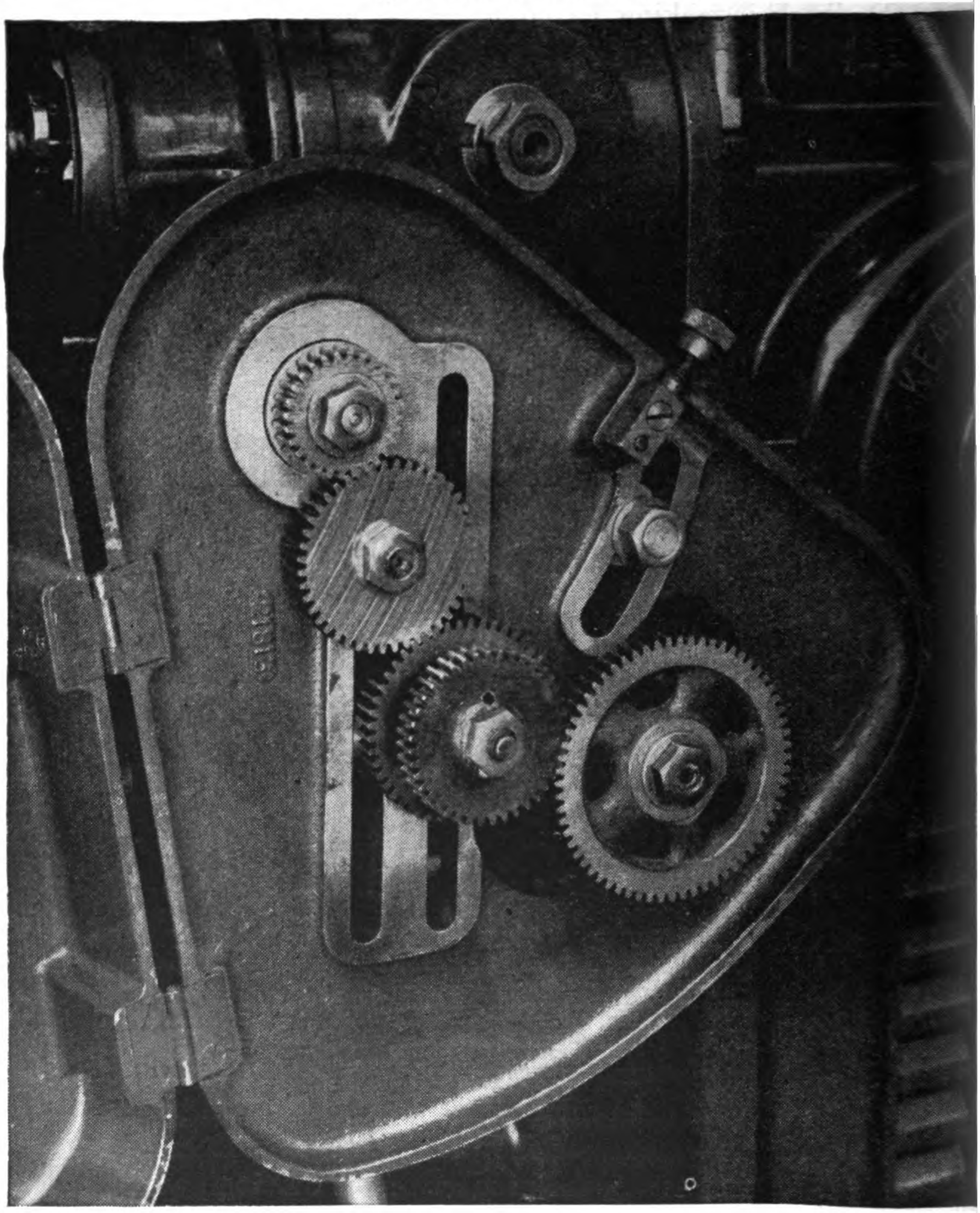
4. The numerators of these fractions represent the number of teeth in the driven gears while the denominators represent the number of teeth in the driving gears; therefore, the driven gears have 36 and 32 teeth respectively, and the driving gears 24 and 40 teeth, respectively.

5. A check on these calculations can be obtained by multiplying the product of the driven gears by 10 and dividing this product by the product of the driving gears. If the result is equal to the desired lead, the gears selected are correct. Thus:

$$\frac{36 \times 32 \times 10}{24 \times 40} = 12$$

6. When a limited number of gears are available, the leads of the helixes that can be cut may be found by substituting the available combinations in the following formula:

$$\text{Lead} = \frac{10 \times \text{product of driven gears}}{\text{product of the drivers}}$$

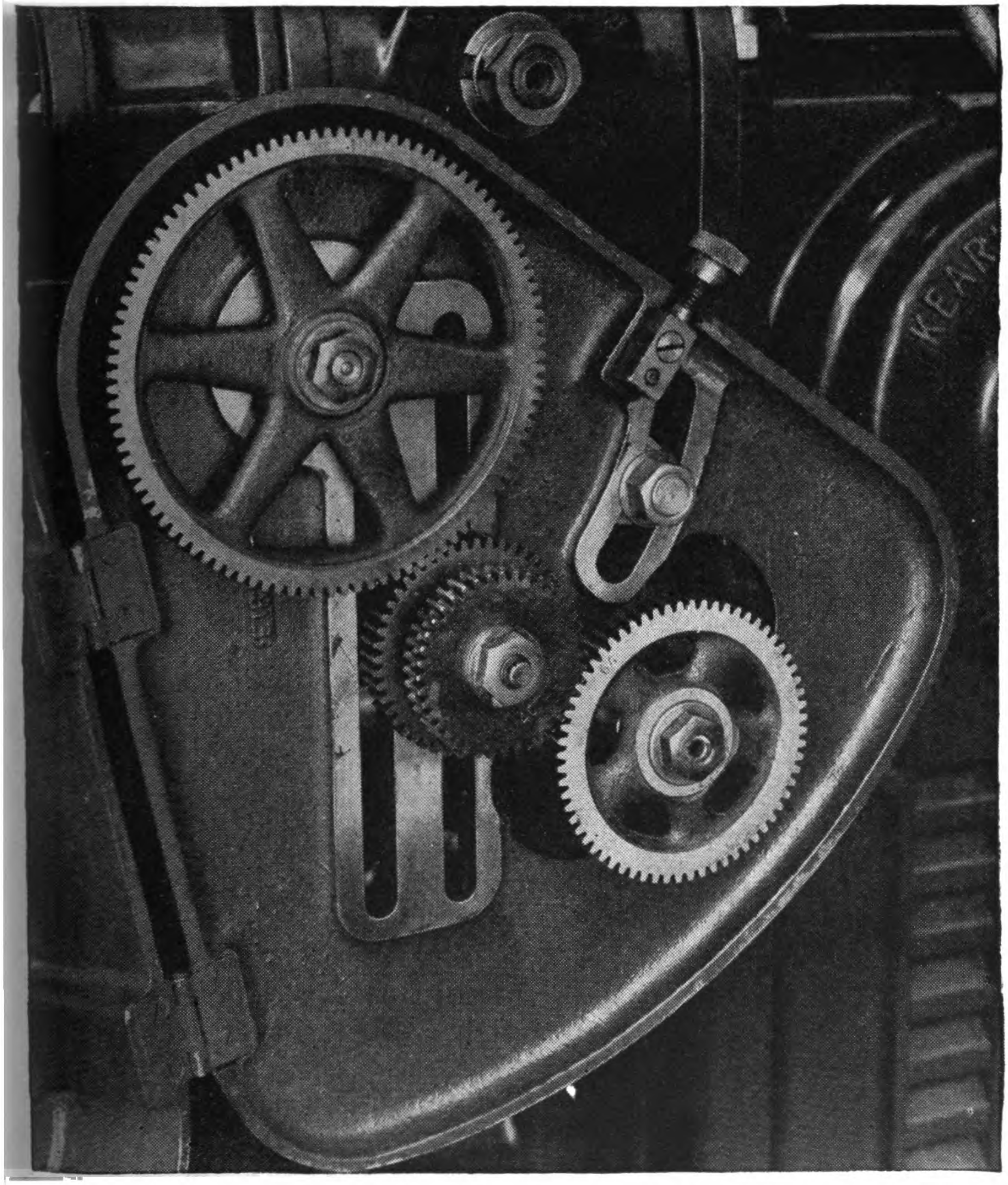


① Arrangement for left-hand helix.

FIGURE 65.—Lead segment set-up for helical milling.

7. When placing gears on the milling machine, driven gears may be exchanged with each other, and driver gears may be exchanged with each other. However, under no circumstances can a driver and driven gear be exchanged.

(4) Since the path of the helix constantly changes its direction, the tooth face of cutters, other than end mills, cannot be perpendicular to



② Arrangement for right-hand helix.

FIGURE 65.—Lead segment set-up for helical milling—Continued.

the work axis. To eliminate tearing of the work brought about by a change of direction, any cutter, excepting an end mill, must be wider at the bottom than at the top of the tooth. An end mill is used when a helical groove having parallel sides is required. When cutting helical flutes in milling cutters, a double angle cutter should be used which has a 12° angle on one side and either a 40°, 48°, or 53° angle on the other. These cutters may be used to cut a tooth angle of 52°, 60°, or 65°, respectively.

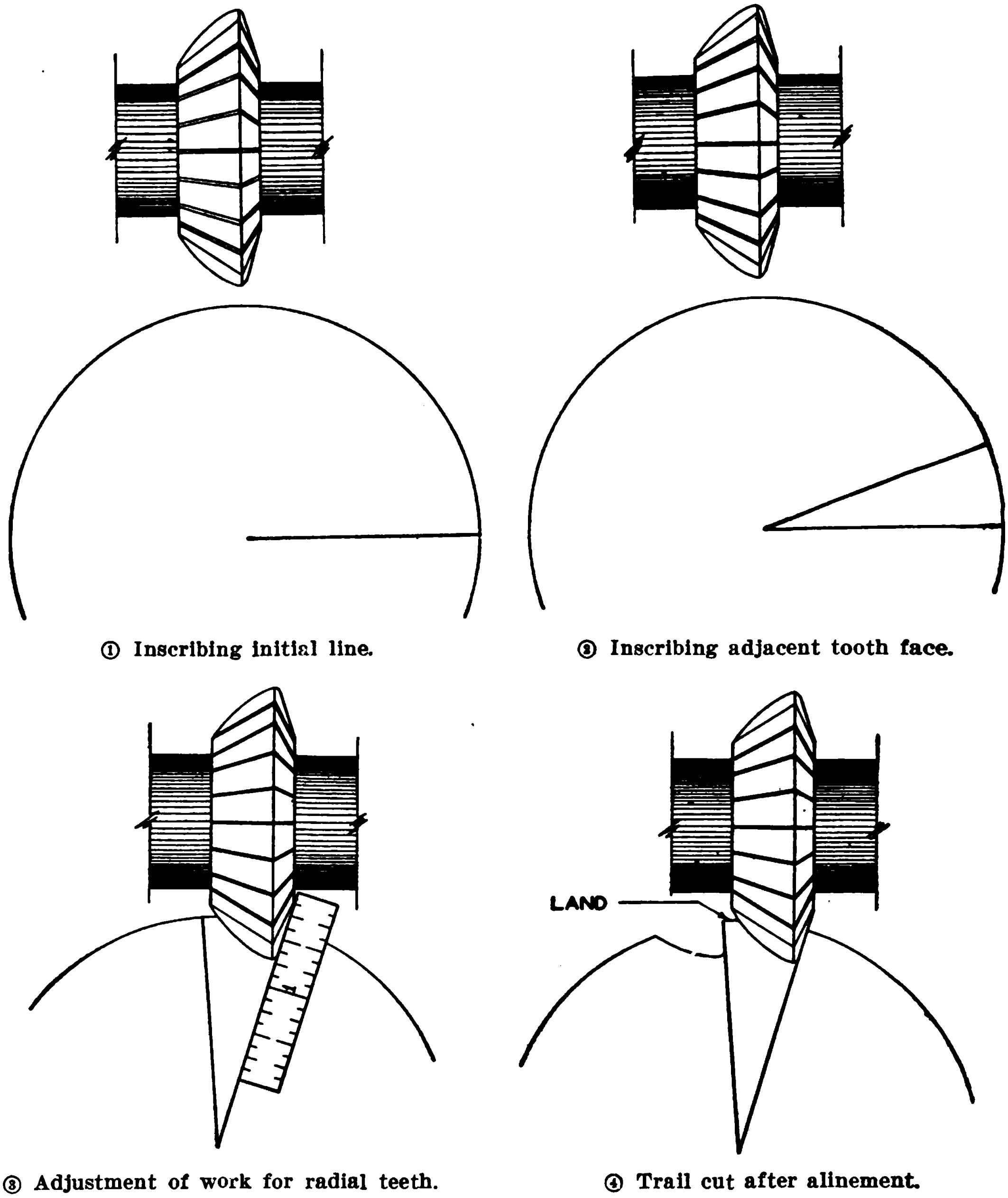


FIGURE 66.—Setting cutter for helical milling of radial teeth.

(5) To position the cutter for helical milling, the following procedure should be used:

(*a*) Place the work between the index centers, install the proper gearing, withdraw the index head stop pin and set the milling machine table at zero.

(*b*) Place the proper cutter on the arbor, and set it centrally with the blank.

1. To set the cutter in position and to proper depth when it is desired to cut an angularly shaped groove in a milling cutter, a line should be inscribed on the end of the blank with a surface gage which has been adjusted to the height of the index centers. After this line has been inscribed, one tooth should be indexed and another line inscribed as shown in figure 66. When fluting a left-hand cutter, the blank should then be rotated 90° plus the 12° cutter

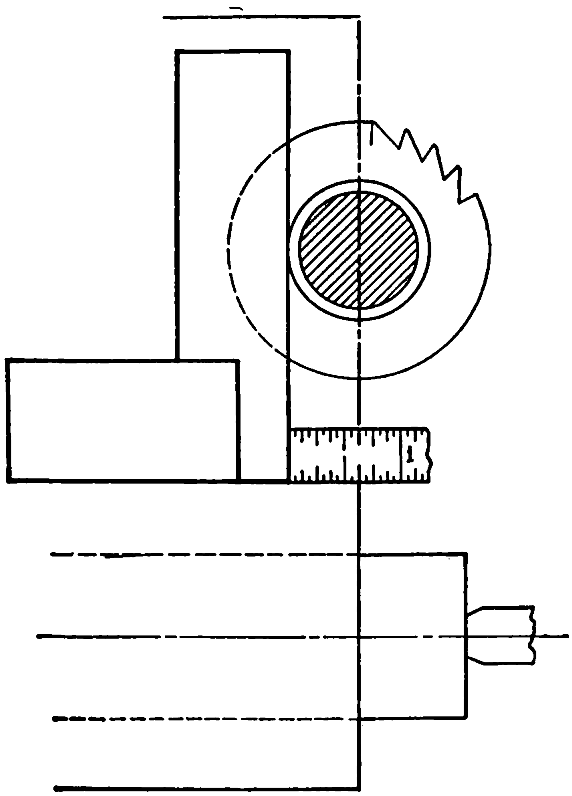


FIGURE 67.—Positioning cutter using steel square.

angle or 102°, while in the case of a right-hand cutter the blank must be rotated 90° minus the 12° cutter angle or 78°. The work should then be adjusted transversely and vertically until the 12° side of the cutter cuts close to the radial line and at the same time leaves the proper width of land. This land width may be determined by measuring the distance between the top of the cut and the line representing the radial face of the next tooth. The longitudinal location of the cutter may be determined by the use of a square placed in contact with the arbor collar, as shown in figure 67, so that the beam of the square rests on the periphery of the work. The cutter is properly set if the distance from the beam of the square to the end of the work is equal to the radius of the arbor collar. It should be remembered that any longitudinal movement of the work table will cause a rotary movement of the work, thus changing the position of the inscribed lines. Consequently, after the table has been located longitudinally, its position must not be changed until the cutter is finally set.

2. A detailed procedure for setting the cutter when milling gear teeth is given in the section on "gear cutting" foun[illegible] later in the text.

Section IV

MILLING OPERATIONS

17. General.—*a*. Milling operations may be classified under fou[illegible] general headings as follows:

(1) Face milling—machining flat surfaces which are at right angle[illegible] to the axis of the cutter.

(2) Plain or slab milling—machining flat surfaces which ar[illegible] parallel to the axis of the cutter.

(3) Angular milling—machining flat surfaces which are at an inclination to the axis of the cutter.

(4) Form milling—machining surfaces having an irregular outline.

b. Explanatory names, such as sawing, slotting, gear cutting, etc., have been given to special operations. Routing is a term applied to the milling of an irregular outline while controlling the work movement by hand feed. The grooving of reamers and taps is called fluting. "Gang" milling is the term applied to an operation in which two or more cutters are used together on one arbor. "Straddle" milling is the erm given to an operation in which two or more milling cutters are ısed to mill two or more sides of a piece at the same time.

18. Face milling.—Figures 10 and 68 illustrate typical face millng operations, the details of which are outlined below.

a. End and side milling cutters are used for face milling operations, he size and nature of the work determining the type and size of cutter required.

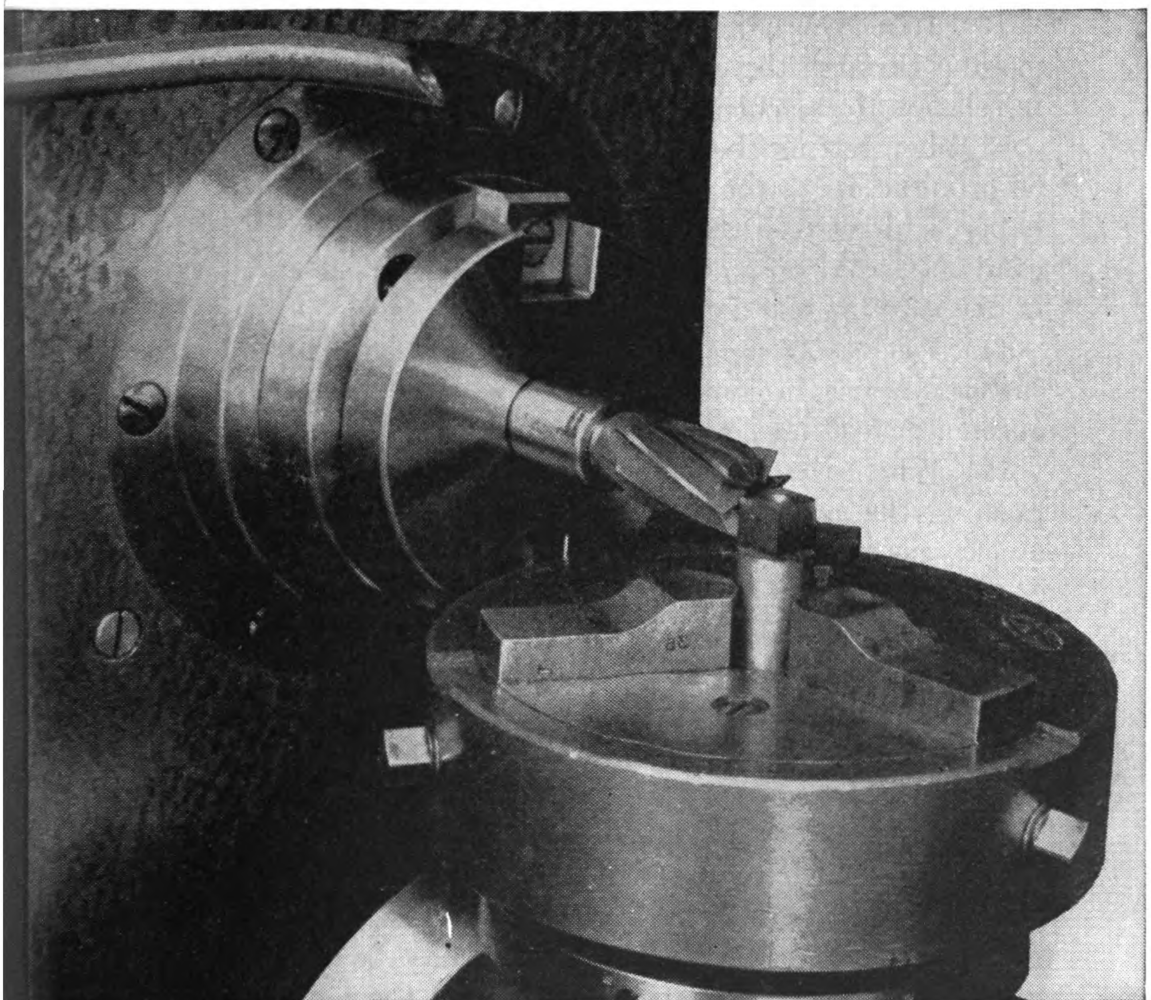


FIGURE 68.—Milling a square with an end mill.

(1) In face milling, the teeth on the periphery of the cutter do practically all of the cutting. However, where the cutter is properly ground, the face teeth actually remove a small amount of stock left from the spring of the work or cutter, thereby producing a finer finish.

(2) It is important in face milling to have the cutter securely placed and to see that all end play of the machine spindle is eliminated.

b. When face milling, the work may be clamped to the table or angle plate or held in a vise, fixture, or jig.

(1) Large surfaces are generally face milled on vertical milling machines, having the work clamped directly to the milling machine table, to simplify handling and clamping operations.

(2) The work should be fed against the cutter in such a way that the pressure of the cut is downward, thereby holding the work agai[illegible] the table.

(3) Whenever possible, the edge of the work should be on a [illegible] passing through the center of the cutter. This position of the w[illegible] in relation to the cutter, helps to eliminate slippage.

c. When setting the depth of cut on a flat surface, the work sh[illegible] be brought up to the cutter so that it will just tear a thin piec[illegible] paper held between the work and the cutter teeth. At this point[illegible] graduated dial on the transverse feed is locked and used as a g[illegible] in determining the depth of cut.

(1) When starting the cut, the work should be moved so that th[illegible] cutter is nearly in contact with the edge of the work, after which th[illegible] automatic feed may be engaged.

(2) When a cut is started by hand, care must be taken to av[illegible] pushing the corner of the work between the teeth of the cutter [illegible] quickly, as this may result in cutter tooth breakage.

(3) In order to avoid any idle time during the operation, the fe[illegible] trips should be adjusted to stop the table travel just as the cutte[illegible] clears the work.

19. Hexagon and square milling.—*a*. When milling a squar[illegible] or a hexagon on a bolt or similar piece, the cutting operation may b[illegible] accomplished by end milling, side milling, or straddle milling. Typ[illegible] ical set-ups for performing this operation are illustrated in figures 6[illegible] and 69. Regardless of the method used, the work should be indexe[illegible] with the index head and the use of the direct indexing method i[illegible] generally recommended. The work may be held in the chuck, o[illegible] centers, or in the chuck and supported by the footstock.

(1) When side milling or straddle milling, the work is usually held in the chuck.

(2) For end milling, the work may be held in the chuck, on centers or in the chuck and supported by the footstock.

(3) Long work, such as a reamer that is to be squared, may b[illegible] mounted between centers or held in the chuck and supported on th[illegible] outer end by the footstock center. The cutter used in this case should be an end mill and the work should be fed vertically. During this

operation the clamp provided at the front of the table should be brought into position to prevent longitudinal movement.

b. Where the number of pieces to be machined warrants the addi-

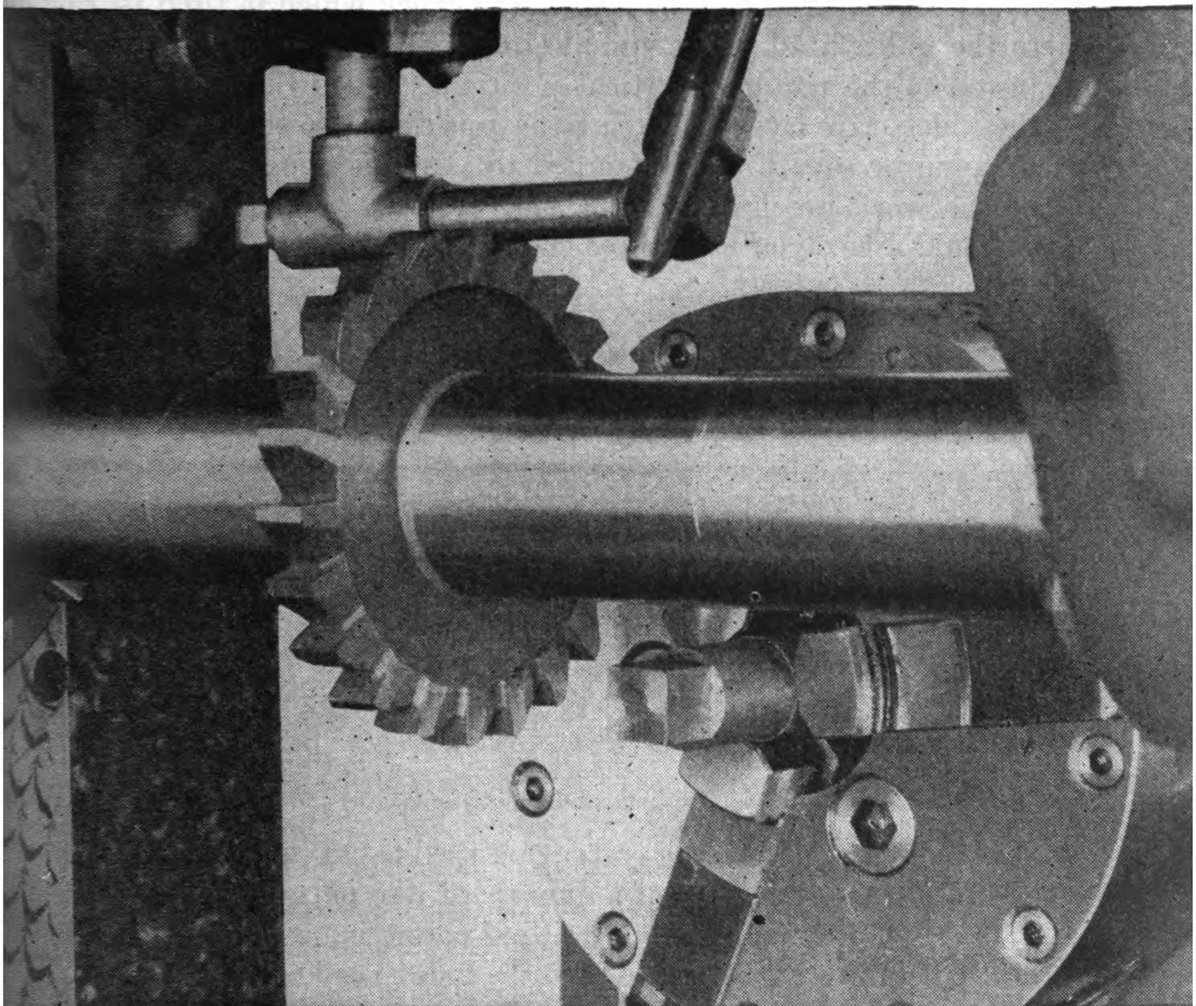


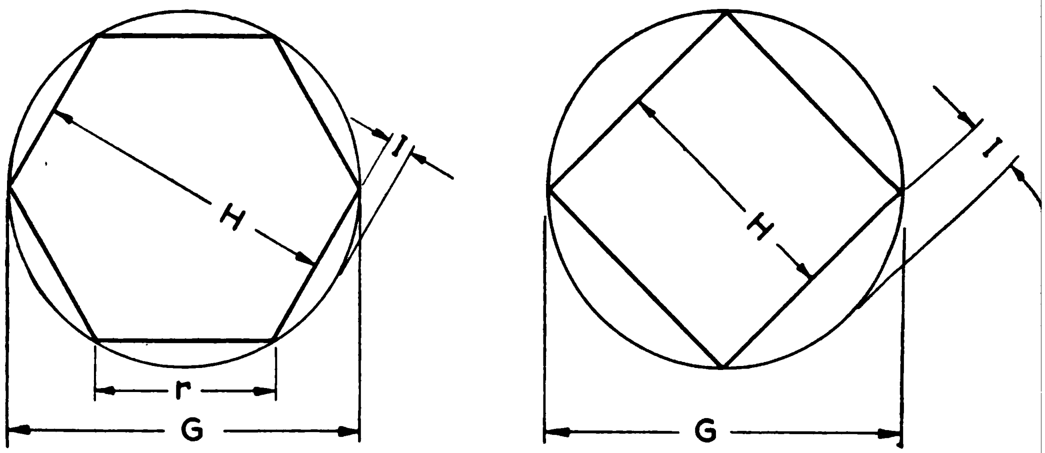
FIGURE 69.—Squaring a shank with a side milling cutter.

tional set-up time required, the work may be held in a vertical position and straddle milled, as illustrated in figure 25.

(1) In this case, a pair of side milling cutters should be used, which

are of like diameter and of such a size that the spacer collar placed between them will clear the work. In adjusting the milling cutters for the proper width of hexagon or square, it may be necessary to use thin paper or metal spacers to obtain the necessary spacing of the cutters.

(2) The work should be held in the chuck which in turn is fastened to the index head. The spindle of the index head may then be adjusted to the required vertical position. When the work is held in the chuck, care must be taken to have it alined so that all sides of the hexagon or square will be milled to the same length. As two sides of the work are finished at a cut, a square is completed with two cuts and a hexagon with three cuts.



① Hexagon. ② Square.

FIGURE 70.—Symbols used in cutting squares and hexagons.

c. Side and end milling cutters are used to cut squares and hexagons except in the production of a number of like parts as described above.

(1) When the side or end milling cutter is used, the work is generally held in a chuck fastened to the index head.

(*a*) The spindle of the index head may be adjusted to either the vertical or the horizontal position. The vertical position is preferred since the work is more easily observed and handled.

(*b*) To eliminate loosening of the chuck when only one cutter is used, the feed should be arranged so that it will operate in a direction that will tend to tighten the chuck thread.

(2) In order to properly set and adjust the milling machine for hexagonal and square cutting, a knowledge of the following factors and calculations is necessary. The various dimensions involved may be determined by reference to figure 70.

(*a*) The size of a hexagon or square is measured across flats, as shown at *H* in the figure.

(*b*) The diagonal of a hexagon G equals 1.155 times the distance across flats H. Thus: $G=H\times 1.155$.

(*c*) The largest hexagon that can be cut from a given cylinder equals the diameter of the cylinder (G) times 0.866. Thus: $H=G\times 0.866$.

(*d*) In milling a hexagon, the length of the flat (r) is equal to one-half the diameter (G). Thus: $r=\frac{G}{2}$

(*e*) The diagonal of a square G equals 1.414 times the distance across flats (H). Thus: $G=H\times 1.414$.

(*f*) The largest square (H) that can be cut from a given cylinder equals the diameter of the cylinder (G) times 0.707. Thus: $H=G\times 0.707$.

(*g*) In milling a square, the depth of cut (I) is equal to one-half the difference between the diameter of the cylinder (G) and the distance across flats (H). Thus: $I=\frac{G-H}{2}$

(3) When milling squares and hexagons it is advisable to take roughing cuts on two opposite sides of the work, after which the work should be moved away from the cutter, the cutter stopped and a measurement made across the flats. The finished dimension should be subtracted from this measurement, and the work moved toward the cutter a distance equal to one-half the difference. The remaining sides of the square or hexagon may then be cut by direct indexing.

(*a*) To safeguard the operator, the work should be measured or put in place only while the machine is shut down.

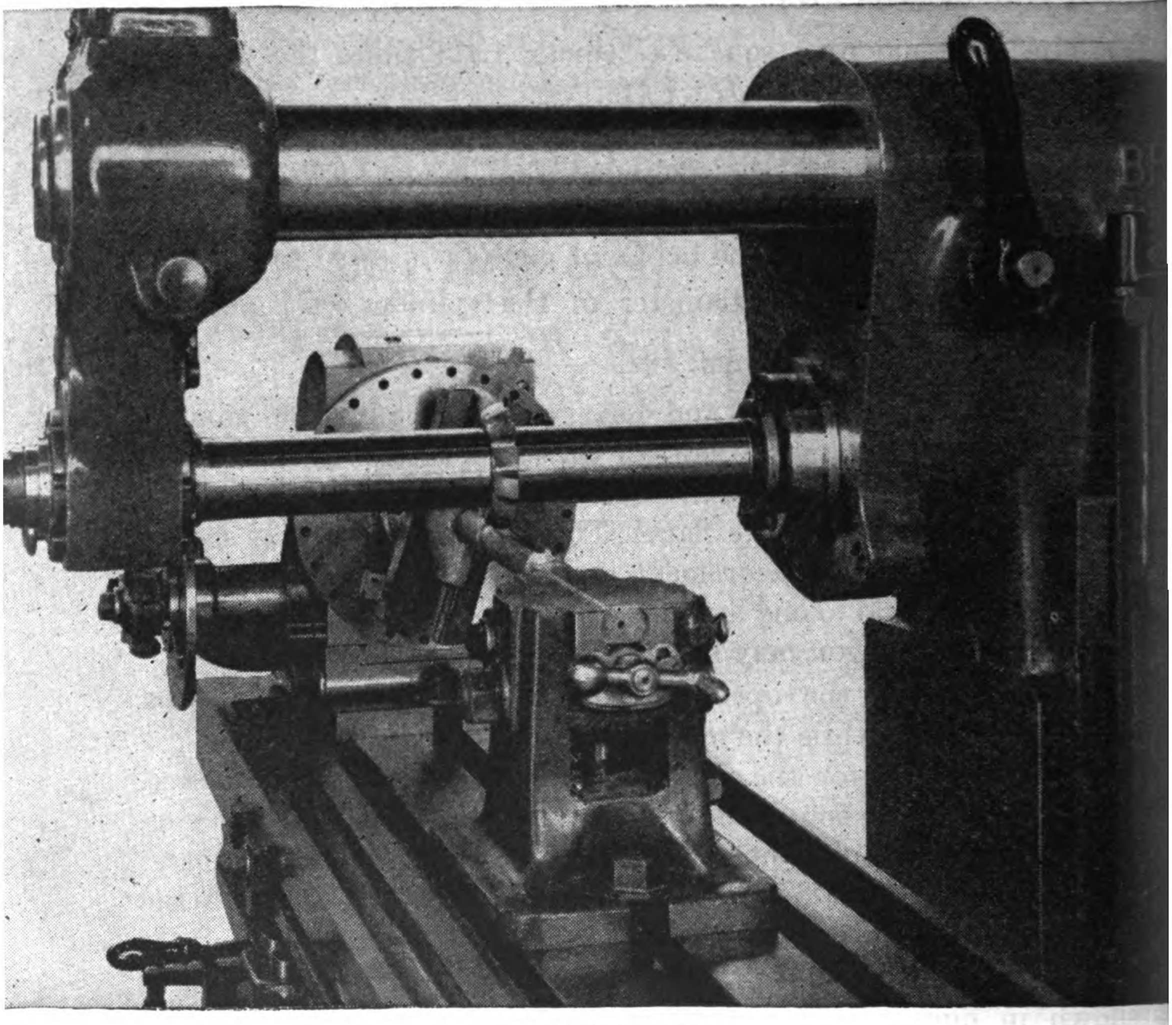
(*b*) When setting for the depth of cut on a cylindrical surface, the same procedure should be used as that described for flat surfaces in the paragraph on face milling. In order to eliminate losses due to backlash, all readings of the dials should be taken with the thrust of the screw in one direction.

20. Reamer milling.—*a*. Straight reamers are grooved or fluted, as shown in figure 71, to provide cutting edges and channels for receiving and discharging chips. The cutting edges produced by fluting should insure the production of a hole that is smooth, round, and of a specified size.

(1) Reamers are very apt to chatter and dig in unless they are properly milled and kept in good condition. Common causes for these two troubles are equal spacing of teeth, too much rake, or too much clearance.

(*a*) The tendency for a reamer to dig in because of the rake of the teeth is overcome by the use of radial teeth or teeth with negative rake. Figure 72 illustrates the cutting of a negative rake tooth while figure 73 shows the cutter setting necessary for milling radial teeth.

(*b*) Wobble and chatter caused by improper type teeth may be overcome by having the proper width of land, using the correct cutter, helical flutes, or straight flutes irregularly spaced.



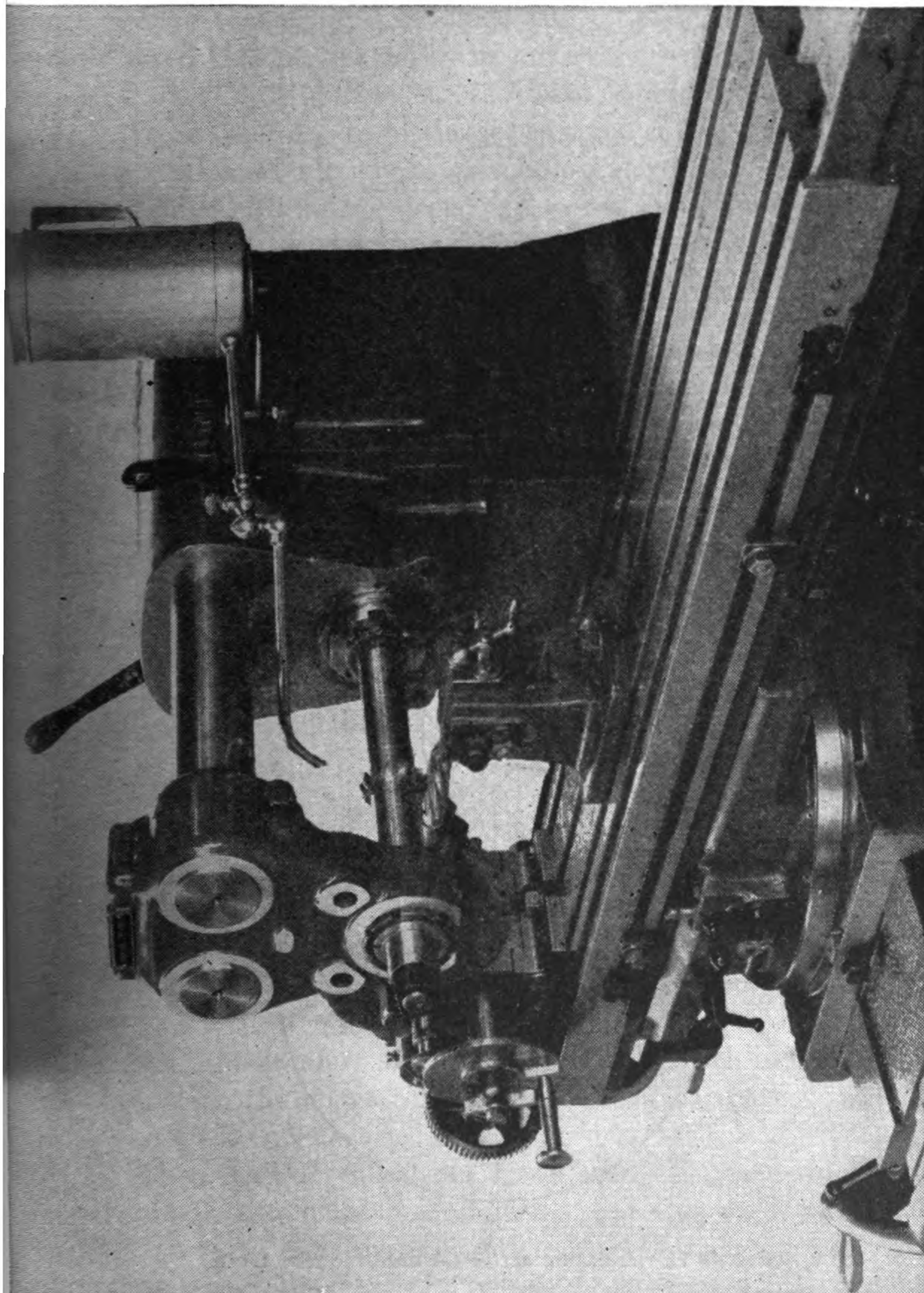
① Straight reamer.

FIGURE 71.—Milling reamer flutes.

(*c*) Irregular spacing of straight cut reamer teeth, as described in a subsequent paragraph is necessary if the above mentioned troubles are to be avoided.

(2) The fluting of reamers is best accomplished with improved form cutters, which produce a groove that is cleanly cut on both sides. The improved form cutter is a combination of the form and angular types, and has an angle of 6° on one side, with a radius on the other ranging

rom $\frac{7}{32}$ inch for a number 1 cutter to $\frac{7}{8}$ inch for a number 8 cutter. 'able III gives the proper cutter selection for various diameter ream-



② Helical reamer.

FIGURE 71.—Milling reamer flutes—Continued.

ers. When using an improved form cutter to cut a groove having one radial side, it is necessary to offset the work laterally as illustrated in figure 66.

Table III.—*Improved form reamer fluting cutters*

Cutter number	Reamer diameter (inches)	Number of reamer flutes
1	$\frac{1}{8}$ to $\frac{3}{16}$	6
2	$\frac{1}{4}$ to $\frac{5}{16}$	6
3	$\frac{3}{8}$ to $\frac{7}{16}$	6
4	$\frac{1}{2}$ to $\frac{11}{16}$	6 to 8
5	$\frac{3}{4}$ to 1	8
6	$1\frac{1}{16}$ to $1\frac{1}{2}$	10
7	$1\frac{9}{16}$ to $2\frac{1}{8}$	12
8	$2\frac{1}{4}$ to 3	14

(*a*) To aline and set the improved form cutter to depth, the blank should be mounted on the index centers and a line inscribed on the end of the blank with a surface gage adjusted to the height of the

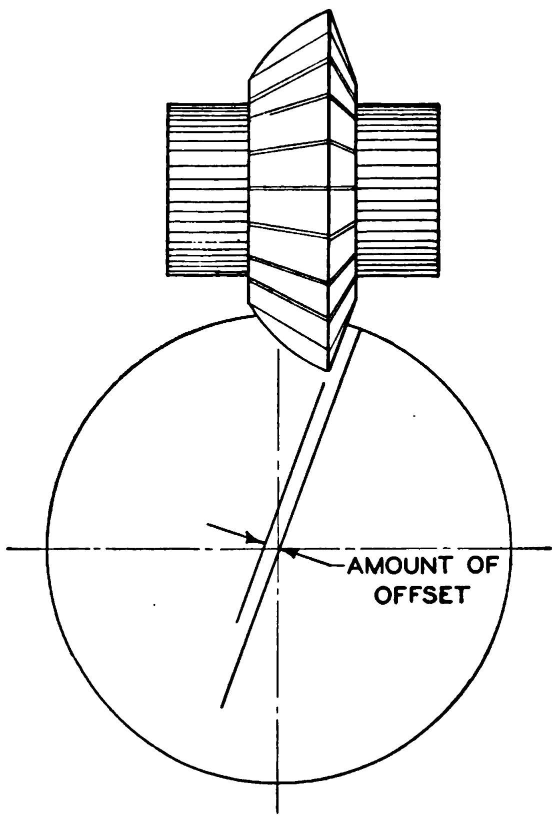


Figure 72.—Locating cutter for negative rake tooth.

index centers. The blank should then be rotated and the 6° angular side of the cutter alined with this inscribed line by placing the edge of a steel scale against the angular cutter tooth as illustrated in figure 66. A short trial cut should then be made in two adjacent teeth, increasing the depth of cut until the proper width of land is provided. The width of the land of the cutting edges, as shown in figure 66, should be approximately 1/32 inch for a 1/4-inch reamer, 1/16 inch for a 1-inch reamer, and 3/32 inch for a 3-inch reamer. It must be remembered that as the depth of cut is increased, the table must be moved transversely if the tooth face is to remain radial.

(*b*) To prevent dig-in of the reamer, the cutter should be set ahead of the radial line to produce a slight negative rake on the tooth. To accomplish this after the cutter has been set as outlined above, the table should be moved transversely to bring the cutter ahead of the radial line as shown in figure 72. The amount of offset required to produce this slight negative rake is given in table IV.

TABLE IV.—*Cutter offset requirements for various size reamers*

Size of reamer (inches)	Offset of cutter (inches)
1/4	0.011
3/8	.016
1/2	.022
5/8	.027
3/4	.033
7/8	.038
1	.044
1 1/4	.055
1 1/2	.066
1 3/4	.076
2	.087
2 1/4	.098
2 1/2	.109
2 3/4	.120
3	.131

(3) Straight reamers may either be milled with helical or straight cut flutes. In the latter case, an even number of irregularly spaced flutes should be used.

(*a*) When helical flutes are to be cut, the procedure discussed in paragraph 16 should be followed. For this operation, the angle of helix must be such that the cutting edges make an angle of from 10° to 15° with the axis of the reamer.

(*b*) The irregular spacing of straight cut teeth is illustrated in figure 74 and is known as breaking up the flutes. The difference between the largest and smallest space should be very slight, not exceeding 6°. The manner in which the breaking up of the flutes is usually done is to move the index head a certain amount more or less than would be required in the case of regular spacing. This may be accomplished by irregularly spacing a number of teeth on half of the reamer, then spacing those on the other half, so that their

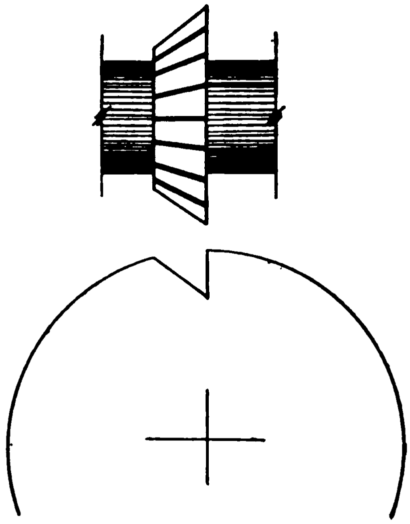


FIGURE 73.—Setting of cutter for milling radial teeth.

cutting edges will be diametrically opposite the ones previously cut. In performing this operation, the indexing is usually done by milling the flutes in pairs; that is, after milling each odd numbered flute, the reamer is rotated one-half a revolution and the diametrically

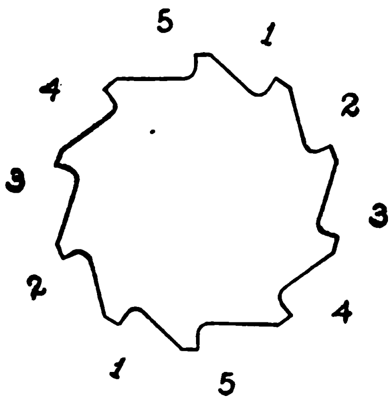


FIGURE 74.—Irregular spacing of reamer teeth.

opposite flute is cut. The amount of movement of the index crank for reamers having various numbers of flutes may be found by referring to table V. When milling irregularly spaced flutes on reamers, it is necessary to raise and lower the table to provide a uniform width of land.

TABLE V.—*Irregular spacing of straight flute reamers*

Number of reamer flute[1]	Number of flutes in reamer				
	6	8	10	12	14
	Number of holes in index plate circle				
	18	18	18	18	54
	Number of full turns and additional holes required for positioning index crank when using above index circles				
2d	20 turns	20 turns	20 turns	20 turns	20 turns.
3d	6 turns plus 14 holes.	4 turns plus 14 holes.	3 turns plus 14 holes.	3 turns plus 10 holes.	2 turns plus 38 holes.
4th	20 turns	20 turns	20 turns	20 turns	20 turns.
5th	6 turns plus 10 holes.	5 turns plus 2 holes.	4 turns plus 2 holes.	3 turns plus 7 holes.	2 turns plus 50 holes.
6th	20 turns	20 turns	20 turns	20 turns	20 turns.
7th		4 turns plus 16 holes.	4 turns	3 turns plus 2 holes.	2 turns plus 40 holes.
8th		20 turns	20 turns	20 turns	20 turns.
9th			3 turns plus 16 holes.	3 turns plus 4 holes.	2 turns plus 52 holes.
10th			20 turns	20 turns	20 turns.
11th				3 turns plus 8 holes.	2 turns plus 44 holes.
12th				20 turns	20 turns.
13th					3 turns.
14th					20 turns.

[1] Starting with the first to be milled, the flutes are numbered consecutively around the reamer.

b. As in the case of straight reamers, taper reamers may have either helical or straight teeth; the latter being the most generally used. In fluting tapered reamers, the operations are the same as those used in cutting straight reamers except that the center line of the work must be out of parallel with the cutting line, so that the width of the land may remain nearly the same throughout its length.

(1) When a tilting table, such as illustrated in figure 18, is available, the work should be held on the index centers which are clamped to the tilting table. The fact that the table may be easily adjusted to bring the center line of the work out of parallel to the cutting line, makes it possible to cut the flute properly without affecting the alinement of the index centers.

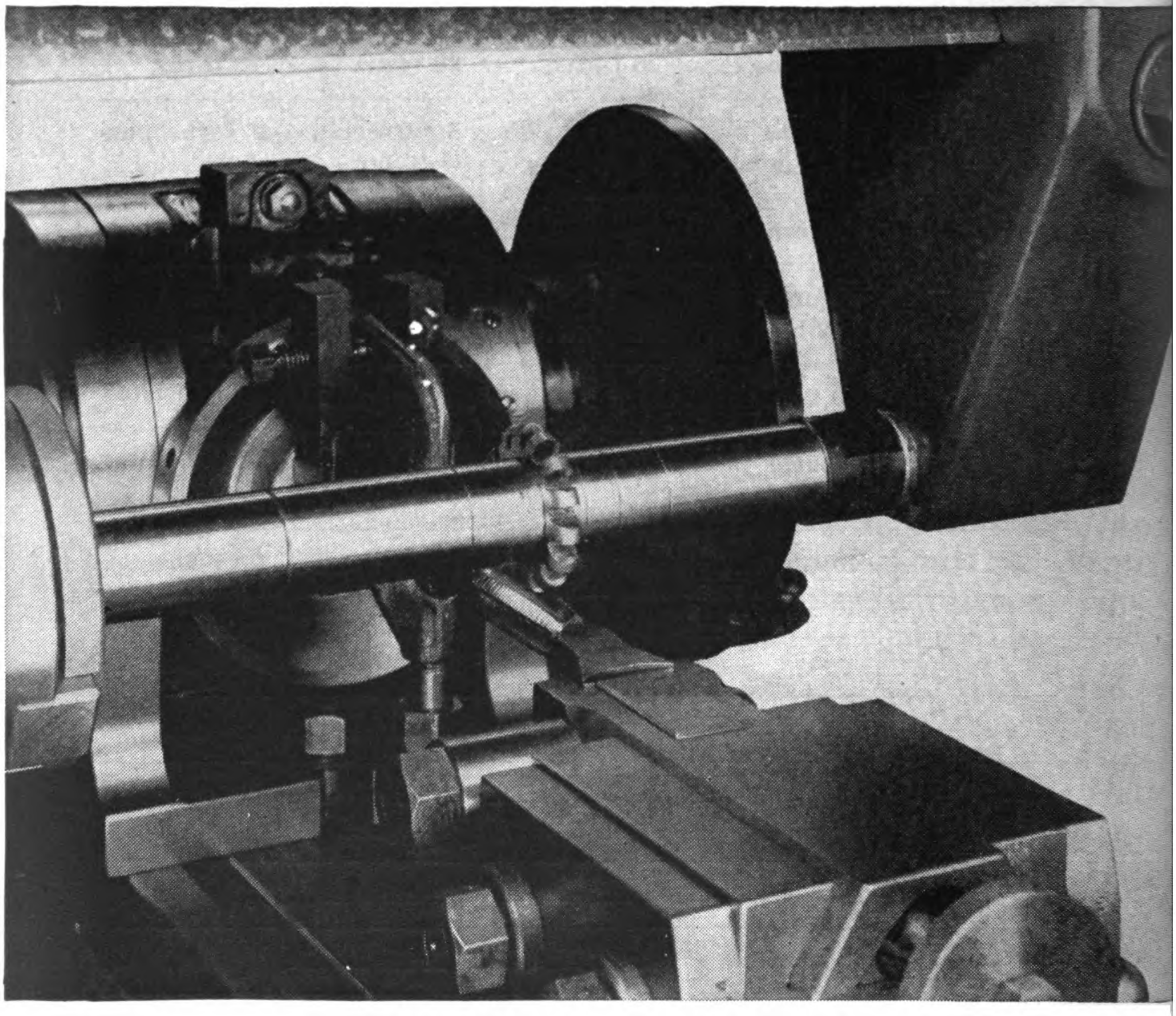


FIGURE 75.—Milling the flutes in a tap.

(2) When a tilting table is not available, taper reamers may be fluted by raising the tailstock center, or by lowering the index head spindle the amount necessary to bring the reamer blank into the proper cutting position.

(*a*) The cut and try method is commonly used to obtain the proper setting of the tailstock or headstock center. This method consists of mounting the reamer on the index centers so that when testing with a surface gage, the large diameter of the tapered portion is a trifle higher than the small diameter end. This setting is accomplished by having the tailstock set above center or the index head set below center, an amount equal to approximately one-fourth the taper of the reamer. Trial cuts are then made on two adjacent teeth to a depth slightly less than that necessary to produce the proper width of land, and readjustments of the center made accordingly.

(*b*) When milling tapers, due to the fact that the tailstock is raised or the index head is lowered as the work is revolved, the tail of the driving dog not only moves around the axis but also along the axis. For this reason it is advisable to use the milling machine dog illustrated in figure 56. Should it be necessary to use a regular bent tail dog, the screw which clamps the tail of the dog in the driver must be loosened before each indexing operation to eliminate springing of the work.

21. Tap milling.—*a.* In the manufacture of taps the grooves or flutes are cut on the milling machine as shown in figure 75. These flutes serve two purposes as they provide the cutting edges and also form channels for receiving and discharging chips. The number of flutes is usually determined by the diameter of the tap, the standard proportions being as follows:

(1) For tap diameters from $\frac{1}{4}$ to $1\frac{3}{4}$ inches, four flutes are generally used.

(2) For tap diameters of $1\frac{7}{8}$ inches and larger, six flutes are generally used.

b. Convex, angular or improved form milling cutters may be used for the fluting operation.

(1) The convex cutter is most commonly used, and produces what is known as the hooked flute. When using the convex cutter for fluting taps having four flutes, the cutter should be selected with a width equal to one-half the diameter of the tap, and the depth of the flute should be one-fourth the diameter of the tap. Table VI gives the sizes and depths of flutes for the various diameter 4 flute taps. Specification for 6 flute taps may be obtained by referring to machinists' handbooks.

(2) Angular cutters have been used extensively in the past, due to the fact that they are cheaper than form cutters of a like size. An angular cutter may also be used for a wider range of tap diameters than a form cutter.

(3) The improved form tap fluting cutter has a cutting edge that is a combination of the angular and the convex forms. This type of

cutter is gaining considerably in popularity since it produces a tap with excellent cutting qualities.

c. When fluting taps, the method of cutter alinement depends on the type of cutter being used.

TABLE VI.—*Specifications for milling four flute taps*

Diameter of tap (inches)	Width of cutter (inches)	Depth of flute (inches)
1/8	1/16	1/32
1/4	1/8	1/16
1/2	1/4	1/8
3/4	3/8	3/16
1	1/2	1/4
1 1/4	5/8	5/16
1 1/2	3/4	3/8
1 3/4	7/8	7/16
2	1	1/2
2 1/4	1 1/8	9/16
2 1/2	1 1/4	5/8
2 3/4	1 3/4	11/16
3	1 1/2	3/4

(1) To aline the convex cutter, the blank is mounted on the index centers and by the use of the surface gage, two lines are inscribed along the axis of the peripheral surface of the blank, equidistant from the center line. The spacing of these lines must be equal to the cutter's width. The blank is then indexed one-fourth of a revolution and the table adjusted to a position which places the line directly under and equidistant from the center of the cutter. With the cutter revolving, the blank should be raised until the cutter leaves tool marks on its periphery. The rotation of the cutter is then stopped to permit examination of the tool marks and lines. If the tool marks are not in the center of the inscribed lines, the table is moved transversely to centralize the cutter. An approximate visual method of alinement may be used where extreme accuracy is not required. This is done by setting the center of the cutter in alinement with the tailstock or index head center as nearly as possible by eye.

(2) Angular and improved form cutters are set in the same manner as reamer fluting cutters. The procedure for this is discussed in paragraph 20.

d. For the fluting operation the tap is usually held and indexed between index centers, and the following is a brief outline of the procedure involved:

(1) Install and aline the index centers on the milling machine table.

(2) Mount and center the proper size milling cutter.

(3) Place the tap between the index centers and, with the cutter revolving, raise the table until the cutter just touches the tap.

(4) Lock the vertical hand feed dial in this position and, using it as a guide, set the machine for the proper depth of cut (see table VI).

(5) Cut the flute to the proper length, using the longitudinal feed screw.

(6) Repeat the cutting operation for the remaining flutes, bringing the work into position by direct indexing.

22. Cutter milling.—Milling machine cutters are generally fluted on the milling machine. To avoid confusion when referring to this operation the term "mill" is used to designate the cutter being machined. The diameter and width of the mill, number and kind of teeth, and the type of cutter used depend upon the size and type of work to be performed by the mill.

a. When the cutting face is to be wider than 4 inches, it is better to make the mill in two or more interlocking sections.

b. Mills larger than 5 inches in diameter are generally fitted with inserted teeth.

c. The number of teeth to be milled is determined by the diameter and type of mill.

(1) Plain mills start with a 2-inch diameter having 14 teeth, and increase 2 teeth for each ½ inch added to the diameter.

(2) Side mills start with a 2-inch diameter having 22 teeth, and increase 2 teeth for each ½ inch added to the diameter.

(3) Coarse end mills have 4 teeth on all sizes up to 1 inch in diameter. Five teeth are used on 1¼-inch mills, 6 teeth on 1½-inch mills, and 8 teeth on 2-inch mills.

d. The type of cutter to be used for the above milling operations depends upon the type of tooth desired.

(1) Plain mills which are to have straight cut teeth should be milled with a 60° angular cutter.

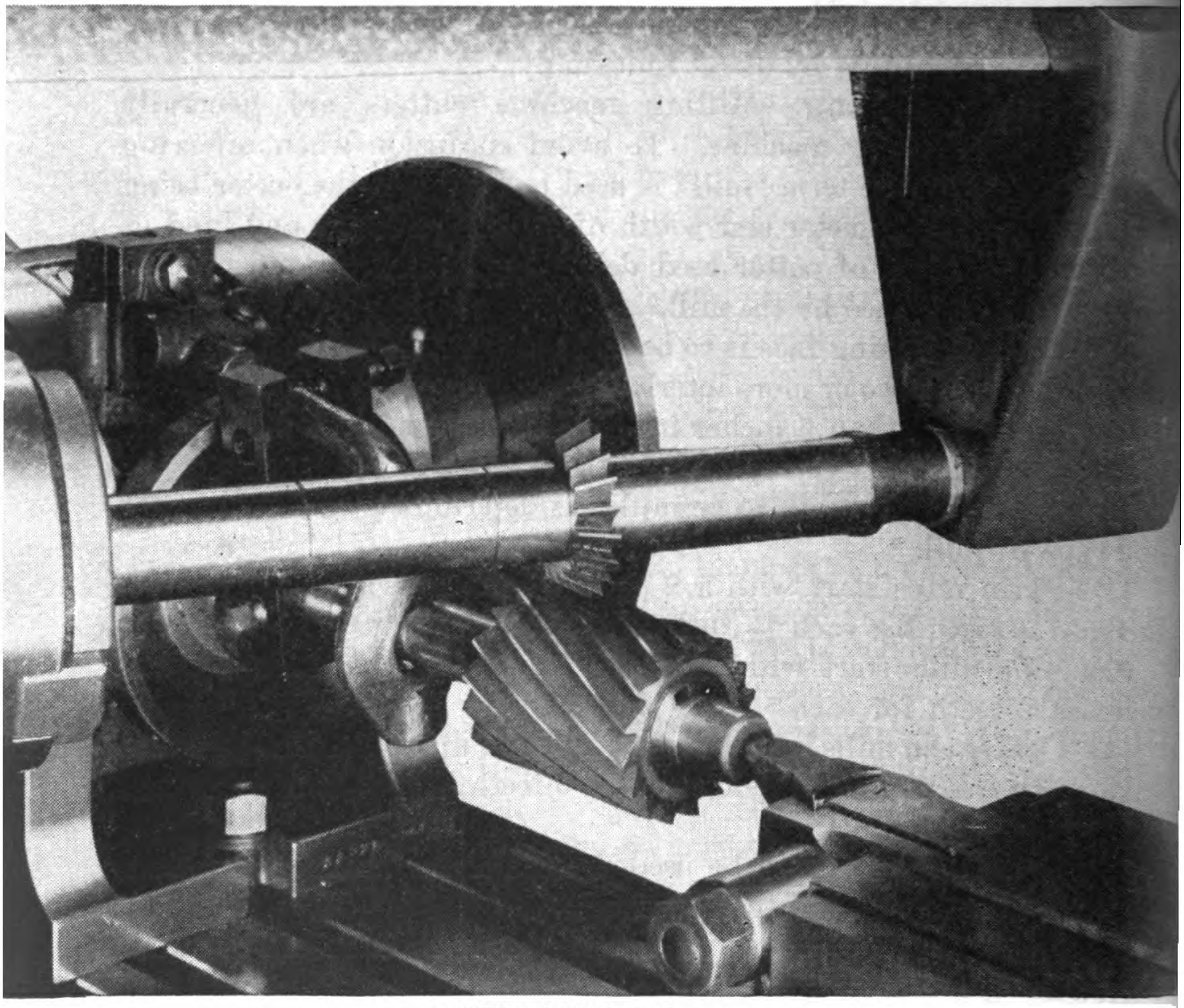
(2) Mills which are to have helical cut teeth should be cut with a 60° or 65° double angular cutter, having a slightly rounded point. The lead of the angle of helix should be approximately 15° when cutting helical teeth.

(3) The side teeth of a wide side mill should be cut with a 70° or 75° angle cutter, while thin mills require the use of an 80° cutter.

e. When cutting flutes in the various types of milling cutters, the work is usually mounted on an arbor and held between the index centers, or held directly in the index head. Mounting the work directly in the head spindle allows it to be swiveled into the various positions required for cutting side, end, or angular mills. Figure 76 illustrates methods of mounting.

f. The method of cutter alinement depends on whether a single or double angle cutter is to be used.

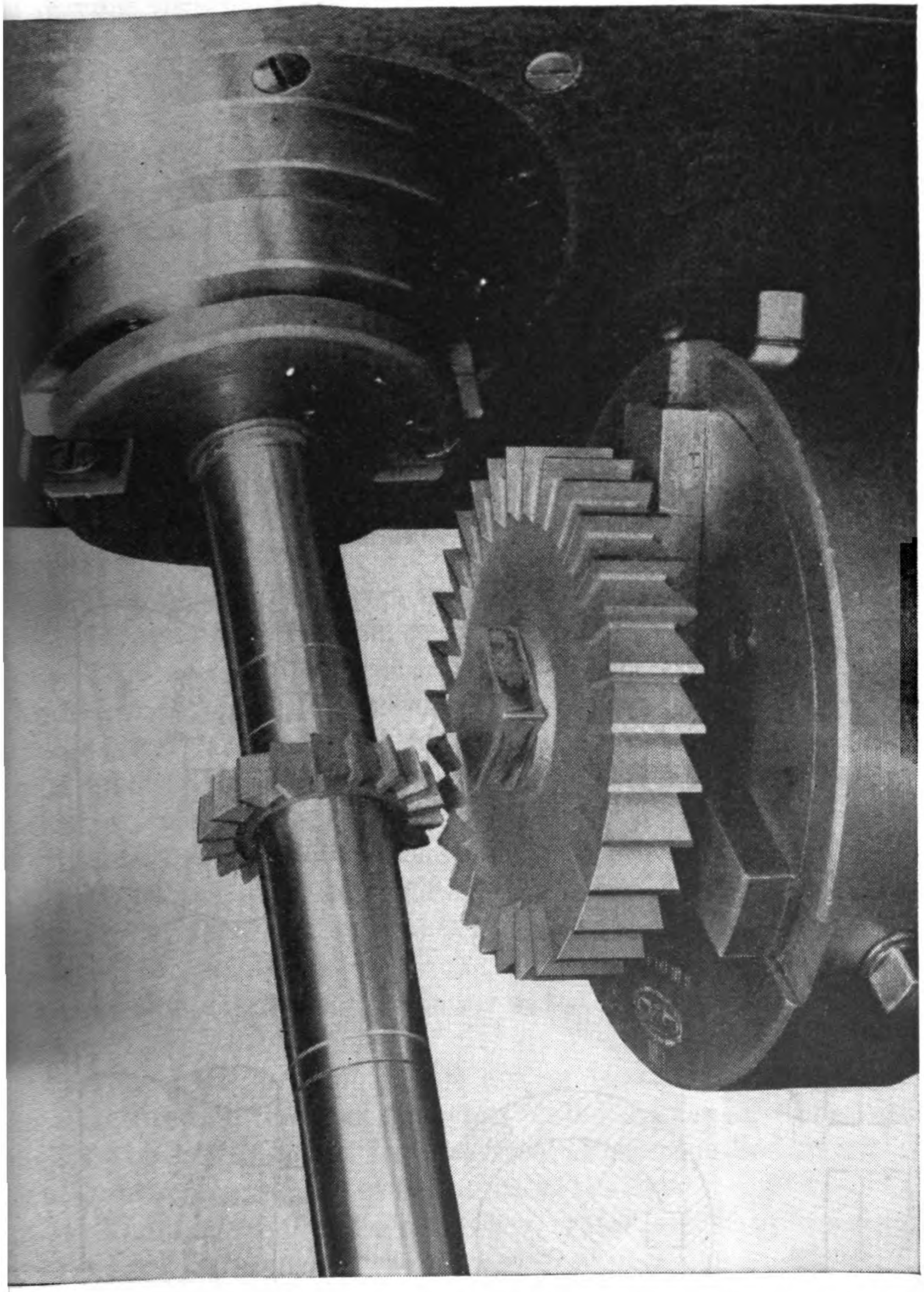
(1) To aline the single angle cutter when cutting radial teeth, the work is held by the index head, and a line is inscribed along the



① Milling helical teeth.

FIGURE 76.—Machining a milling cutter.

peripheral surface of the work parallel to the axis, and at the same height as the centers of the index head. The work is then indexed ten turns or one-fourth of a revolution, which brings the line on top center; after which, the milling machine table is adjusted to a position which places the line approximately under one edge of the cutter. With the cutter revolving, the table is raised until tool marks are made on the periphery of the work, then moved transversely to bring the line to the edge of the cutter. The depth of cut is determined y the width of land between two adjacent tooth spaces. Adjustment or depth is made by taking a light cut through the first tooth pace, then indexing the work and repeating the operation at the



② Milling side teeth.
FIGURE 76.—Machining a milling cutter—Continued.

next tooth space. These cuts may be alternately increased in depth until the correct width of land is obtained, and the remaining tooth spaces milled at this setting.

(2) The setting of a double angle cutter for position and depth has previously been discussed in paragraph 16*b*(5).

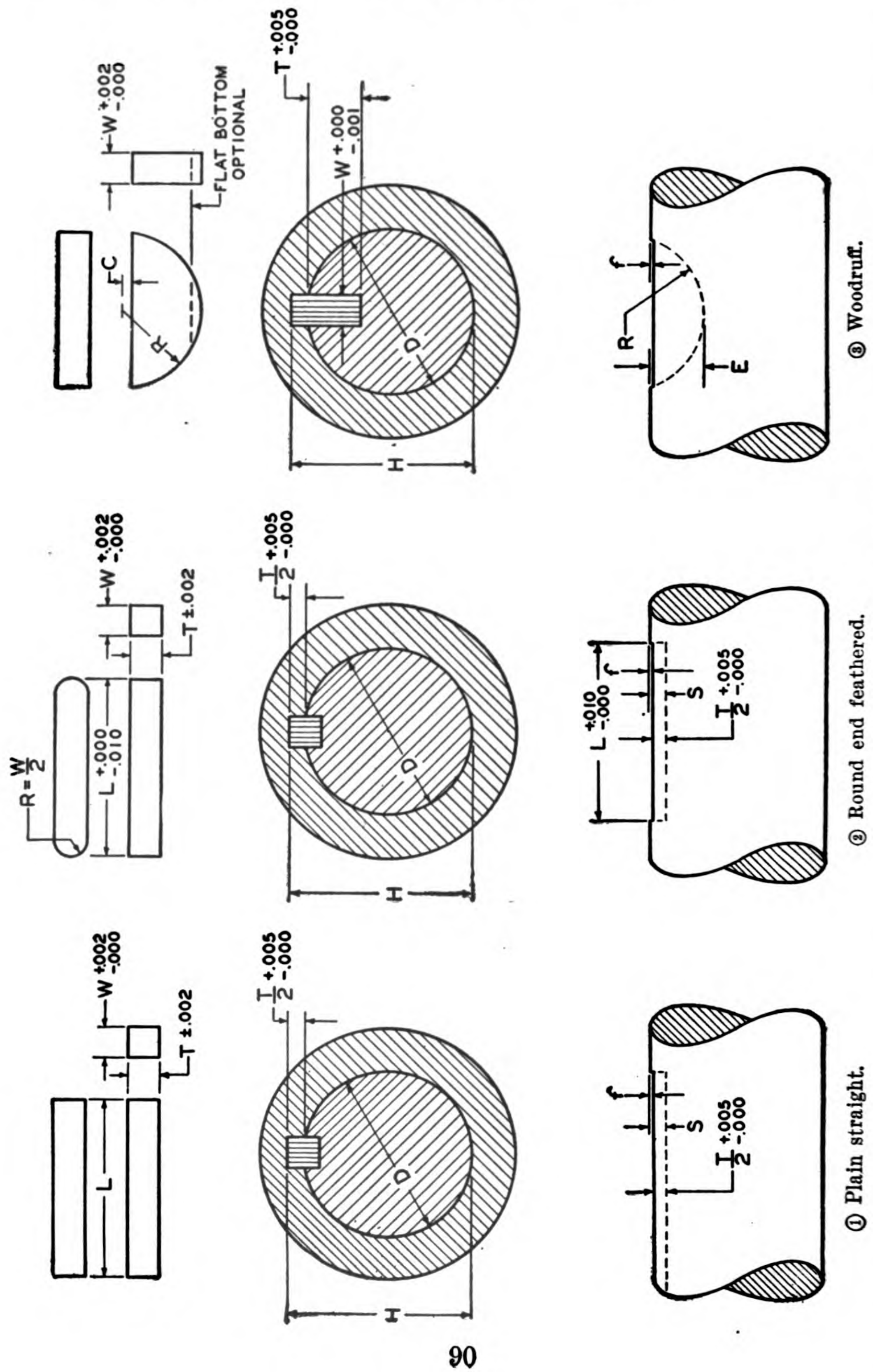


FIGURE 77.—Types of keys and keyseats.

23. Keys and keyseat milling.—*a.* Keyseats are grooves of different shapes cut along the axis of the cylindrical surface of a shaft, into which keys are fitted, to provide a positive method of locating and driving members mounted on the shaft. A keyway must be machined in the mounted member to receive the key.

b. The type of key and corresponding keyseat to be used depends upon the class of work for which it is intended. The most commonly used types, however, are the plain straight, round end feathered, and Woodruff. These keys are illustrated in figure 77, and are usually made from SAE 1035 or SAE 2330 steel.

(1) Plain straight, or sunk keys, shown in figure 77(1) may be either square or rectangular in shape. For the purpose of interchangeability and standardization, keys are usually proportioned with relation to the shaft diameter. The following rules are widely used to determine sunk key sizes:

(*a*) The key width equals $\frac{1}{4}$ of the shaft diameter.

(*b*) The key thickness equals $\frac{1}{6}$ of the shaft diameter.

(*c*) The minimum length of the key equals $1\frac{1}{2}$ times the shaft diameter.

(*d*) The depth of a square keyway is $\frac{1}{2}$ the width of the key.

(2) Round end feathered, or Pratt and Whitney keys, as shown in figure 77(2) are similar to plain straight keys, except that they have rounded ends. The dimensions of the key are designated by a number or letter, and may be determined by referring to machinists' handbooks. The key thickness is $1\frac{1}{2}$ times its width, while the length is from a minimum of twice the width of key to a maximum of 4 inches plus the width of key.

(3) Nordburg keys are cylindrical in shape and have a taper of $\frac{1}{16}$ inch per foot. In general practice, the key is made $\frac{1}{4}$ the shaft diameter for shaft sizes up to and including 6 inches. Due to the fact that this key is not used in aircraft construction, no illustration is given.

(4) Woodruff keys (fig. 77(3)) are semicircular in shape, and are manufactured in various diameters and thicknesses. The circular side of the key is seated in a keyseat which is milled in the shaft with a cutter having the same radius as the key.

(*a*) The size of the Woodruff key is designated by a system of numbers which represent the normal key dimensions. The last two digits of the number indicate the diameter of the key in eighths of an inch, while the digits preceding them indicate the width of the key in thirty-seconds of an inch. Thus, a number 404 key would be $\frac{4}{8}$ or $\frac{1}{2}$ inch in diameter and $\frac{4}{32}$ or $\frac{1}{8}$ inch wide, while a number

1012 key would be $\frac{12}{8}$ or $1\frac{1}{2}$ inches in diameter and $\frac{10}{32}$ or $\frac{5}{16}$ inch wide. The proper dimensions for various size Woodruff keys are given in table VII.

(*b*) In order that proper assembly of the keyed members may be made, a clearance is required between the top surface of the key and the keyway. This clearance may be from a minimum of 0.002 inch to a maximum of 0.005 inch although 0.003 inch is the desired value. Positive fitting of the key in the keyseat is provided by making the key 0.0005 to 0.001 inch wider than the seat.

TABLE VII.—*Sizes of Woodruff keys and keyseats*

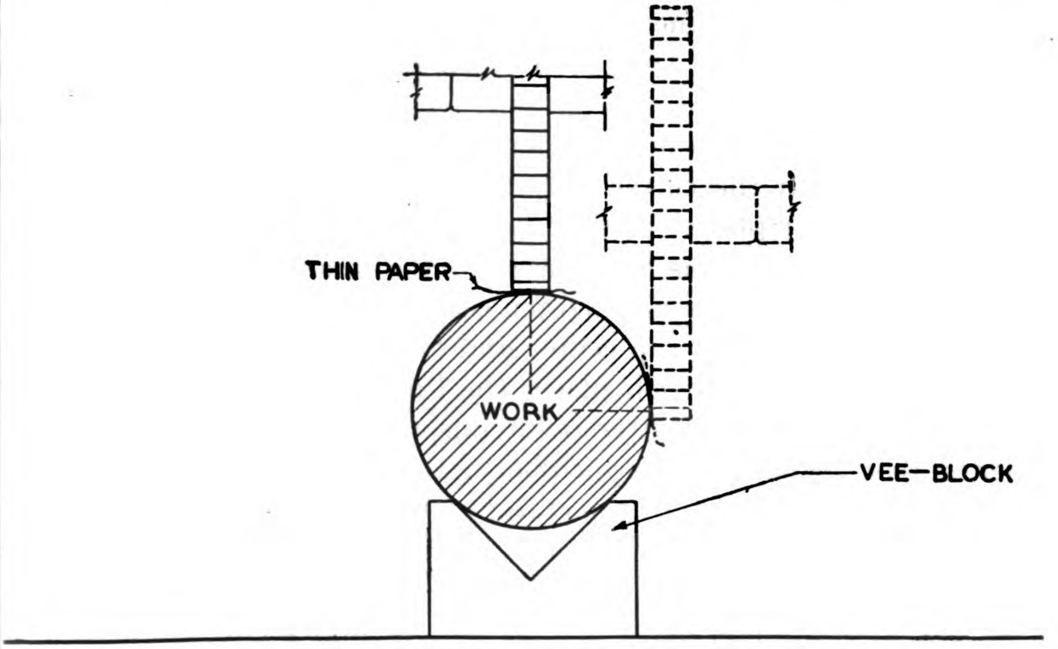
Key number [1]	Key		Shaft diameter		Height of key	Depth of slot
	Width	Diameter	Minimum	Maximum		
204	1/16	1/2	5/16	3/8	3/64	0.1718
304	3/32	1/2	7/16	1/2	3/64	.1561
305	3/32	5/8	7/16	1/2	1/16	.2031
404	1/8	1/2	9/16	3/4	3/64	.1405
405	1/8	5/8	9/16	3/4	1/16	.1875
406	1/8	3/4	11/16	3/4	1/16	.2505
505	5/32	5/8	13/16	15/16	1/16	.1719
506	5/32	3/4	13/16	15/16	1/16	.2349
507	5/32	7/8	7/8	15/16	1/16	.2969
606	3/16	3/4	1	1 1/8	1/16	.2193
607	3/16	7/8	1	1 5/16	1/16	.2813
608	3/16	1	1	1 7/16	1/16	.3443
609	3/16	1 1/8	1 3/16	1 7/16	5/64	.3903
808	1/4	1	1 1/2	1 5/8	1/16	.3130
809	1/4	1 1/8	1 1/2	1 3/4	5/64	.3590
810	1/4	1 1/4	1 1/2	1 3/4	5/64	.4220
812	1/4	1 1/2	1 1/2	1 3/4	7/64	.5160
1011	5/16	1 3/8	1 13/16	2	3/32	.4378
1012	5/16	1 1/2	1 13/16	2 1/2	7/64	.4848

[1] When the key number is preceded by the letter *H*, it indicates that the key is made from 2330 steel. When no letter precedes this number, the key material is 1035 steel. All key dimensions are in inches.

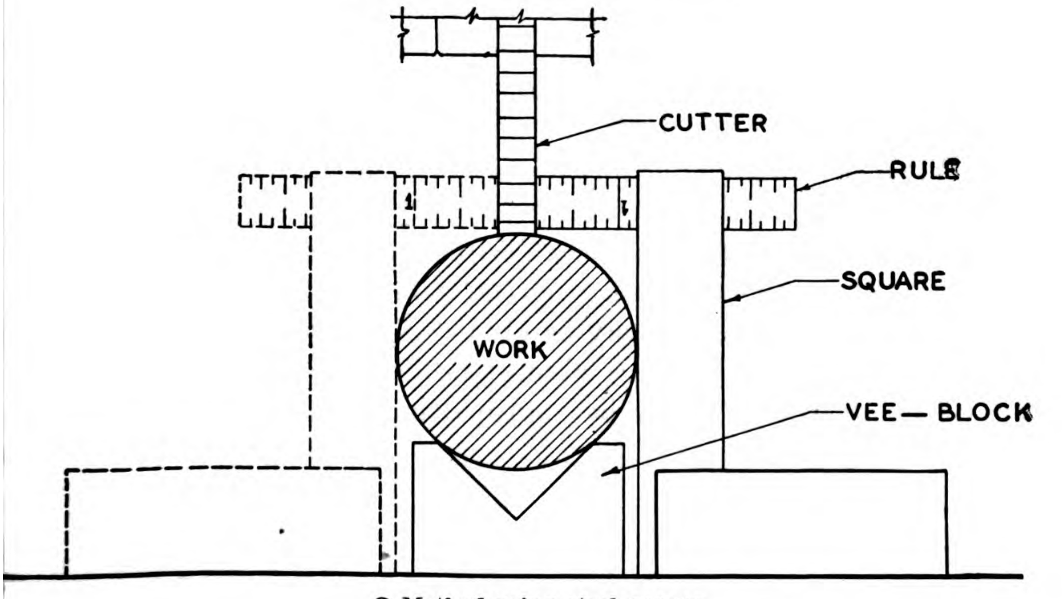
c. Keyseats and keyways may be cut on the milling machine, shaper, planer, keyseating machine or by drilling, slotting, and broaching.

(1) When milling keyseats and keyways, the shaft may be held in the vise, chuck, between centers, or clamped to the milling machine table. The cutter must be set centrally with the axis of the work and this alinement is accomplished by using one of the following methods:

(*a*) When using a Woodruff or side milling cutter, the shaft should be brought up so that the side of the cutter is tangent to the circumference of the shaft. This is accomplished by moving the shaft



① Method using thin paper shim.



② Method using steel square.

FIGURE 78.—Setting cutter for keyseat milling.

transversely to a point, which just permits it to tear a thin piece of paper held between the work and the cutter side teeth, as shown in figure 78①. At this point, the graduated dial on the transverse feed is locked, the milling machine table is lowered and, by using the transverse feed graduated dial as a guide, the shaft is moved transversely a distance equal to the radius of the shaft plus one-half the width of the cutter.

End mills may be alined centrally by first causing the work to contact the periphery of the cutter, then proceeding as in the above operation.

(*b*) When the work is held so that it can be revolved by the index head, alinement of the cutter may be accomplished by inscribing a line along the peripheral surface of the work parallel to the axis, and at the same height as the centers of the index head. After this has been done the work is indexed ten turns or one-fourth of a revolution to bring the line on top center and the milling machine table is adjusted to a position which places the line directly under one edge of the cutter. With the cutter revolving, the work is raised in order to leave tool marks on its periphery, then moved transversely to bring the line to the edge of the cutter. At this point, the graduated dial on the transverse feed is locked and used as a guide in moving the work transversely, one-half the width of the cutter.

(*c*) An approximate or visual method of alinement may be used where extreme accuracy is not required. This is done by setting the cutter as near center as is possible by eye and making the final alinement, by measuring the distance between the blade of a square set against the shaft and the sides of the milling cutter, as illustrated in figure 78②.

(2) When milling square and rectangular keyseats in a shaft, the depth T is measured from a line passing through the upper corners of the keyseat. The total depth S is equal to the distance T plus the additional depth (f) caused by the curvature of the shaft. The values for the distance (f) may be obtained for the various standard shaft sizes from table VIII. Should table values not be available, value of the factor (f) may be obtained by means of the following formula:

$$f=R-\sqrt{R^2-\left(\frac{1}{2}W\right)^2}$$

Where: R=radius of shaft
W=width of key

(3) The depth of cut S can be measured by using the outside micrometers, vernier calipers, or, where the width of key W prevents the use of the micrometers directly, the measurement can be

made by placing the proper size key in the keyseat and measuring the dimension, as shown at *H* in figure 77①.

(4) When milling keyseats, lines showing the position and the length of the keyseat to be cut should be inscribed and center punched on the shaft, to assist the operator in the cutting operation.

TABLE VIII.—*Values of factor (f) for various size shafts*

Diameter of shaft (inches)	Width of key (inches)									
	1/16	3/32	1/8	5/32	3/16	7/32	1/4	5/16	3/8	D^2
	Factor (f) (inches)									
1/4	0.004	0.009	0.016	------	------	------	------	------	------	0.0625
3/8	.003	.006	.011	0.017	0.025	------	------	------	------	.1406
1/2	.002	.004	.008	.013	.018	0.025	0.033	------	------	.2500
5/8	.001	.003	.006	.010	.014	.019	.026	0.042	------	.3906
3/4	.001	.003	.005	.008	.012	.016	.022	.034	0.051	.5625
7/8	.001	.002	.004	.007	.010	.014	.018	.028	.042	.7656
1	.001	.002	.004	.006	.009	.012	.015	.024	.036	1.0000
1 1/8	------	.002	.003	.005	.008	.011	.014	.022	.032	1.2656
1 1/4	------	.002	.003	.005	.007	.010	.013	.019	.029	1.5625
1 1/2	------	.001	.002	.004	.006	.008	.011	.016	.024	2.2500
1 3/4	------	.001	.002	.003	.005	.007	.009	.014	.020	3.0625
2	------	.001	.002	.003	.004	.006	.008	.012	.017	4.0000
3 1/2	------	.001	.002	.003	.004	.005	.006	.009	.014	12.250

(5) The actual milling operation for cutting the three standard types of keyseats are as follows:

(*a*) A plain straight keyway or keyseat is milled with a plain milling cutter, or a Woodruff cutter. The work should be properly mounted, the cutter centrally located, and the work raised by using the hand vertical feed, until the revolving cutter tears a piece of thin paper held between the peripheral teeth of the cutter and the work. At this point the graduated dial on the vertical feed is locked and the work moved longitudinally to allow the cutter to clear the piece. The vertical hand feed screw is then used to raise the work the total depth of cut. After this adjustment, the knee of the machine should be locked, and the cut made by feeding the table longitudinally.

(*b*) Round end feathered keyways are generally cut by means of an end or cotter mill, although roughing cuts, in large keyways, may be made with a plain milling cutter. As in the case of plain straight keyways, the work should be properly mounted and the cutter centrally located with respect to the piece. The work is then moved to permit the end of the cutter to tear a piece of thin paper held between the cutter and the work. At this point the graduated feed dial should be locked and used as a guide for setting the cutter to the total depth. The ends of the keyseat should be well marked and the work moved back and forth, making several passes to eliminate error due to spring of the cutter.

(*c*) Keyseats for Woodruff keys are cut with special Woodruff cutters as shown in figure 79. They are designated in the same

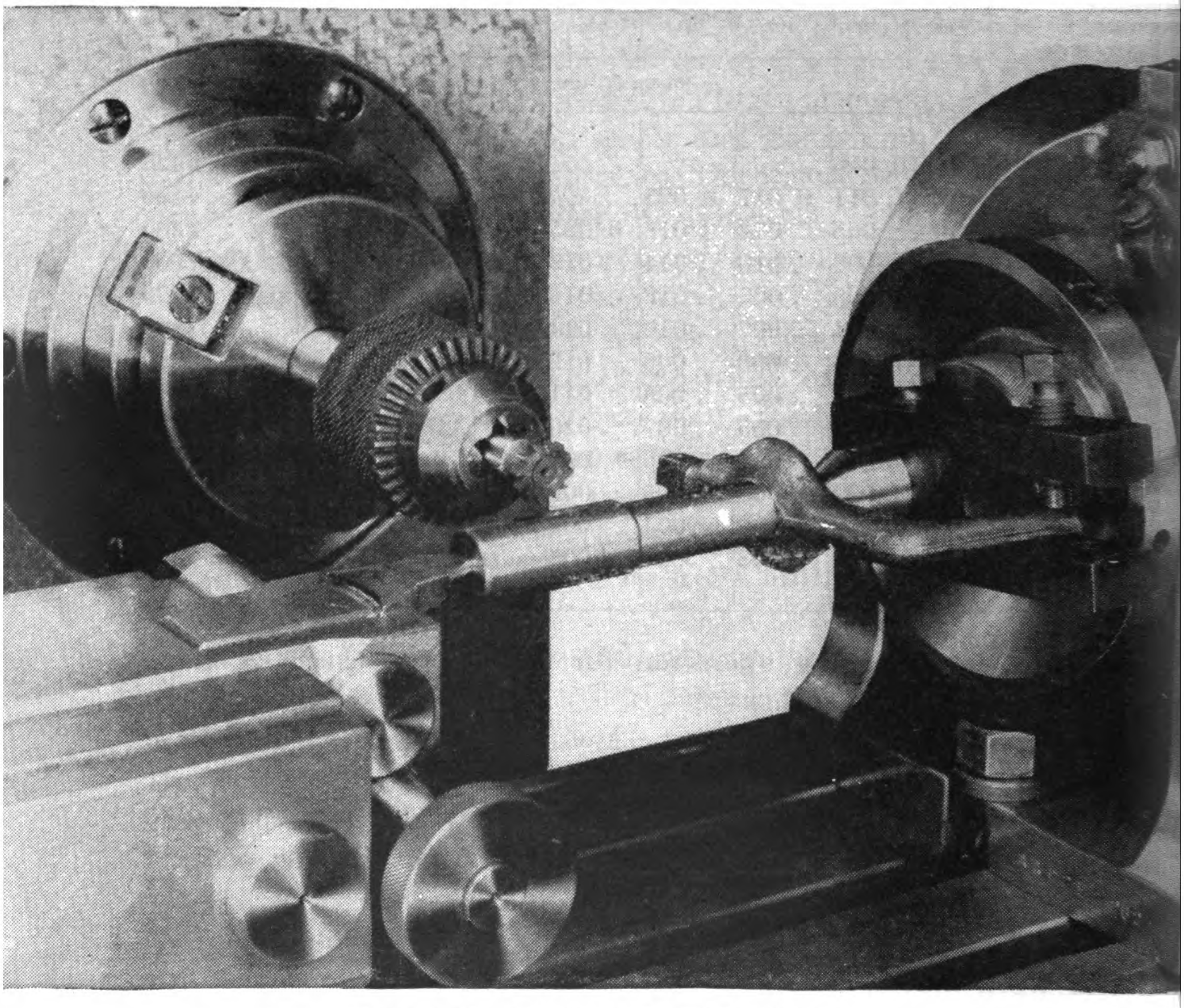


FIGURE 79.—Milling a Woodruff keyseat.

manner as the key for which they are intended; thus, a No. 607 cutter would be required for cutting a keyseat for a No. 607 key. The cutter is mounted in a spring collet or drill chuck which has been inserted in the spindle of the milling machine. With the cutter located over the position in which the keyway is to be cut, the work should be raised by using the hand vertical feed until the revolving cutter tears a piece of thin paper held between the peripheral teeth of the cutter and the work. At this point the graduated dial on the vertical feed should be locked and the clamp on the table set. Using the vertical feed, with the graduated dial as a guide, the work is raised until the full depth of the keyseat is cut, completing the operation. Should specifications for the depth of cut not be available, the correct value may be determined by means of the following formula:

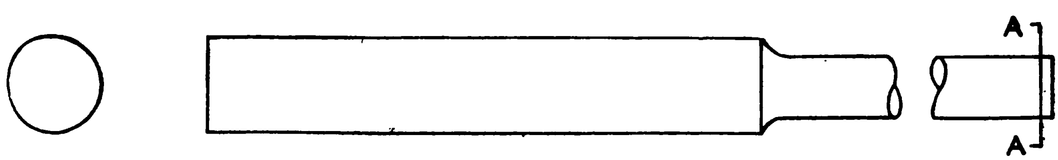
$$E=R-\left(\frac{W}{2}+C\right)$$

Where: E=depth of cut
R=radius of key
W=width of key
C=cut below center

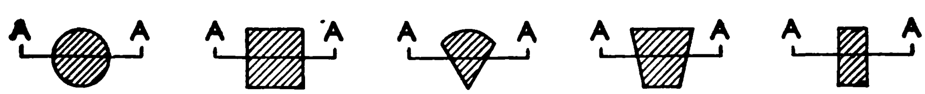
d. For rapid production, internal keyways are usually cut by means of keyseating machines. However, in the general shop, internal keyways may be cut on the milling machine by using a slotting attachment.

(1) Slotting attachment, as illustrated in figure 14, is used to cut various shaped grooves with a reciprocating single point tool and may be set so that the movement of the tool is either horizontal or vertical. The setting is determined by the amount of visibility obtainable and the method in which the work must be held. The slotting attachment ram is driven by an adjustable crank which allows the length of stroke to be changed. The ram should be adjusted to permit the tool to clear the work on both ends and care must be taken to prevent the tool from striking any part of the set-up when making the cut.

(2) Tools used for slotting are similar to those required for shaper operations and a set consisting of various special shapes is illustrated in figure 80. These tools have cylindrical shanks which permit them to be secured in the tool holder.



① Side view of tool.



② Cross sectional view of tool ground to various shapes.

FIGURE 80.—Slotting tools.

(3) When slotting, the work is usually held in the vise or in a chuck mounted on the index head as shown in figure 81. Large parts

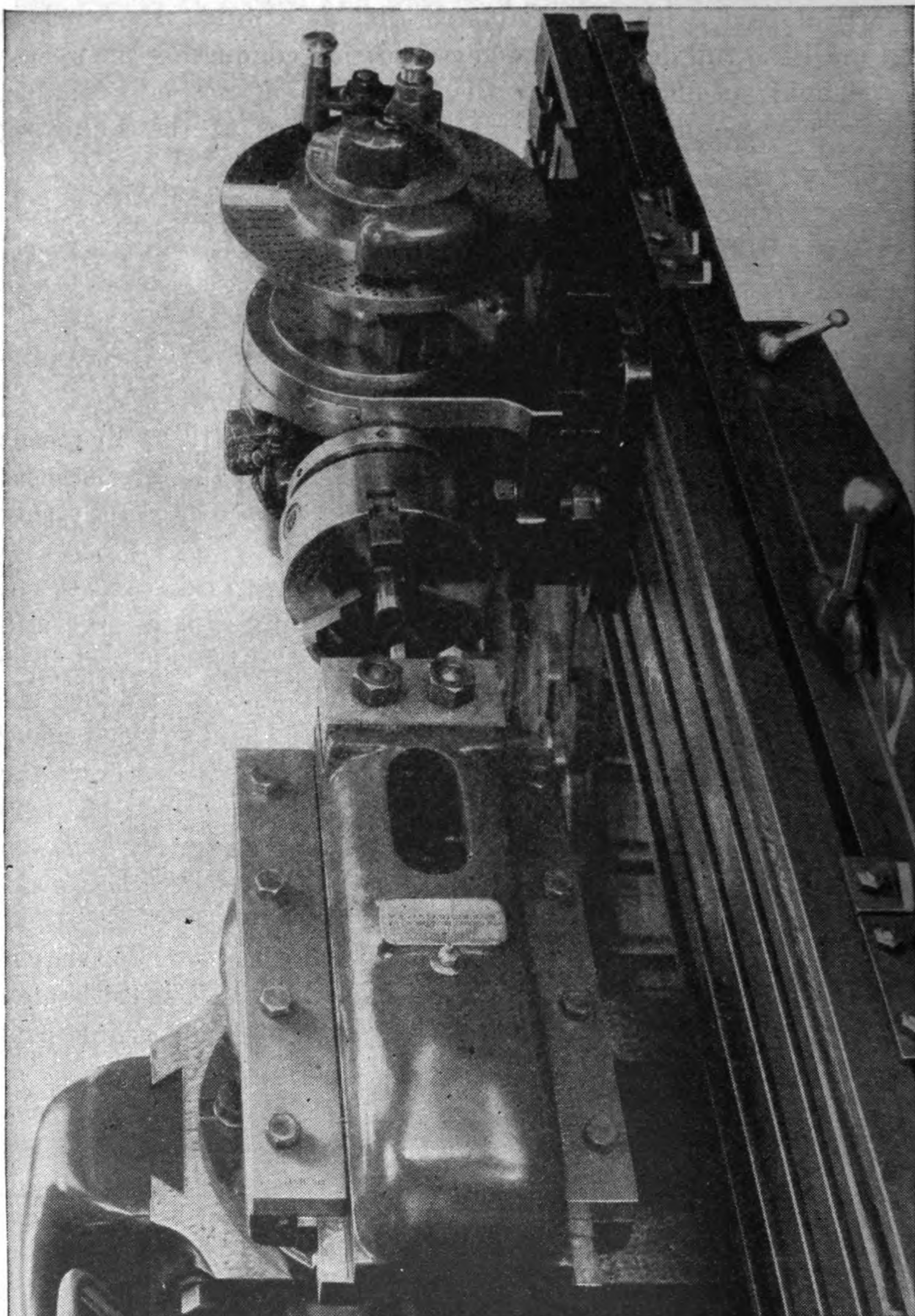


FIGURE 81.—Typical slotting operation.

may be mounted on the circular attachment or clamped directly to the table.

24. Spline cutting.—External and internal splines used in transmission drives, aircraft engine crankshafts, and propeller hubs are generally cut by hobbing and broaching on special machines. However, where splines are to be cut for a repair job, the operations may be accomplished, as shown in figure 82, in a manner similar to that

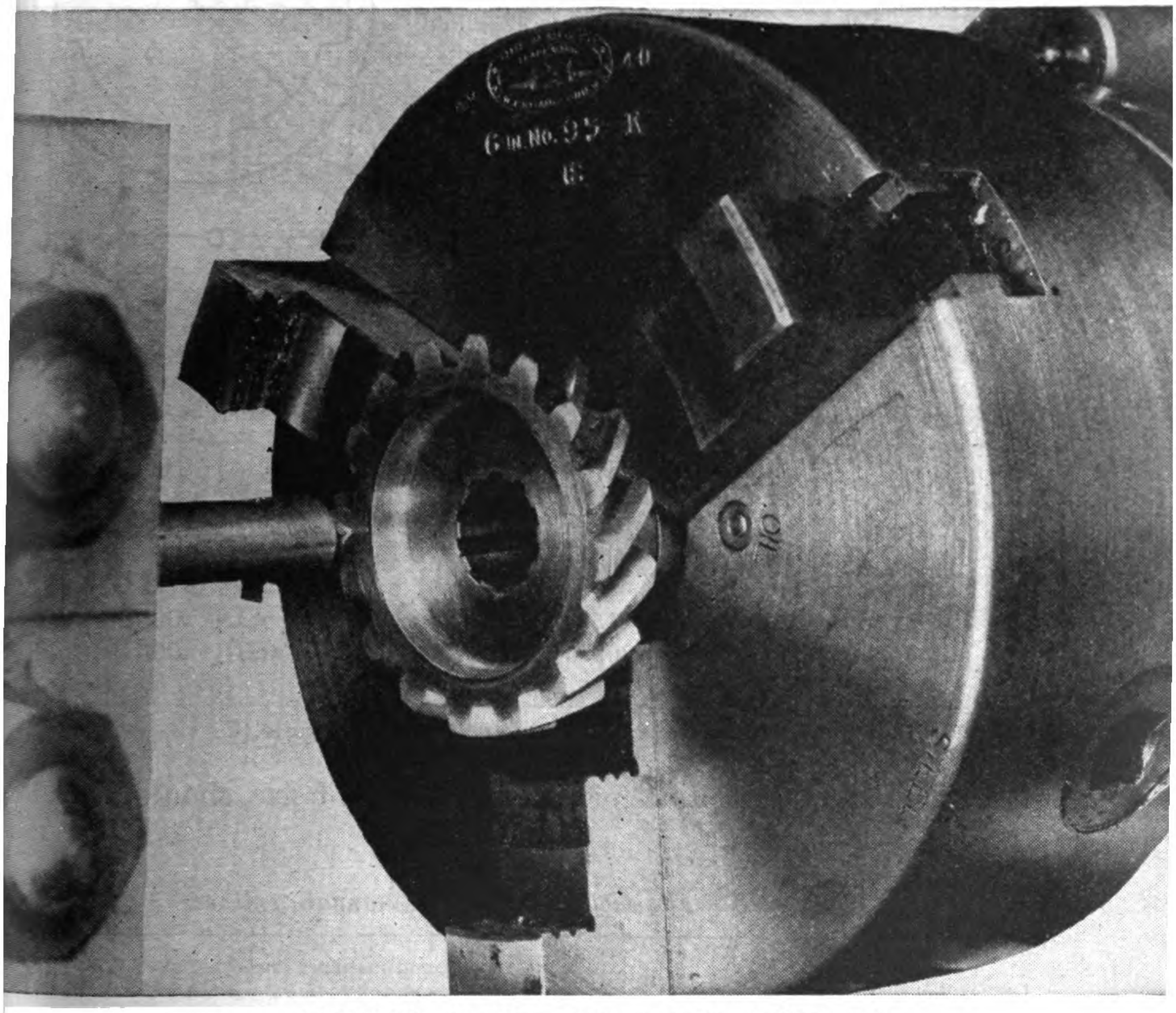


FIGURE 82.—Slotting spline ways in a helical gear.

required for cutting keyways and keyseats. Two standard splines are illustrated in figure 83.

a. The work that the splines are to perform determines their dimensions as these values depend upon whether the parts are to have a permanent or sliding fit, and if a sliding fit, whether or not, they are to slide under load. Table IX gives spline dimensions for the circumstances described above.

b. The allowable tolerances depend both on the size of the shaft and the number of splines to be cut. Tolerance values are given in table X for the various standard numbers of splines.

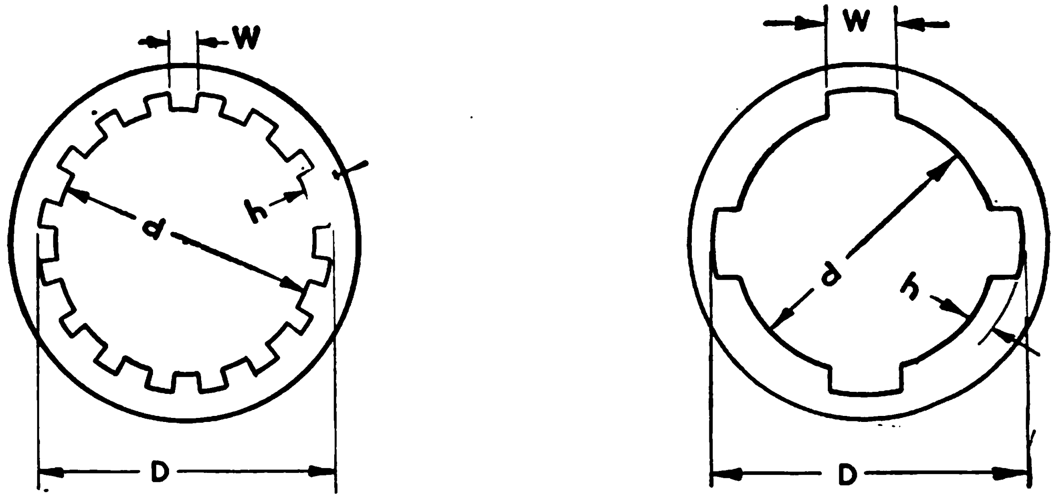


FIGURE 83.—Standard types of splines.

TABLE IX.—*Standard spline dimensions in terms of shaft diameter (D)*

Number of splines	Permanent fit			Sliding fit (no load)			Sliding fit (under load)		
	W[1]	h[1]	d[1]	W	h	d	W	h	d
4	0.241D	0.075D	0.850D	0.241D	0.125D	0.750D	-------	-------	-------
6	.250D	.050D	.900D	.250D	.075D	.850D	.250D	0.100D	0.800D
10	.156D	.045D	.910D	.156D	.070D	.860D	.156D	.095D	.810D
16	.098D	.045D	.910D	.098D	.070D	.850D	.098D	.095D	.810D

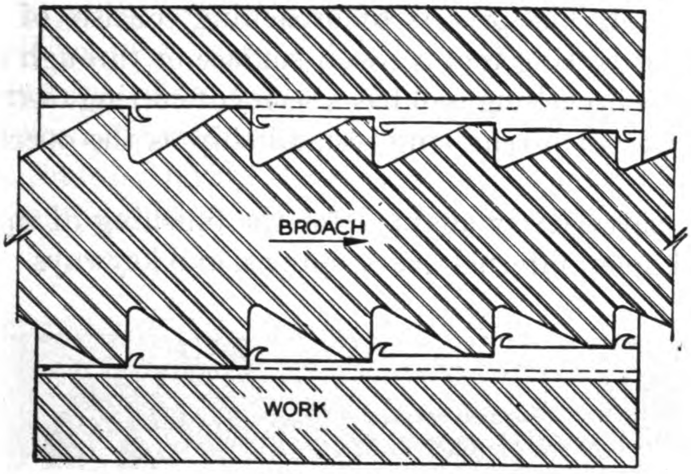
[1] For identification of terms *W*, *h*, and *d*, reference should be made to figure 83.

c. The radii on all spline corners, regardless of size, should be 0.015 inches.

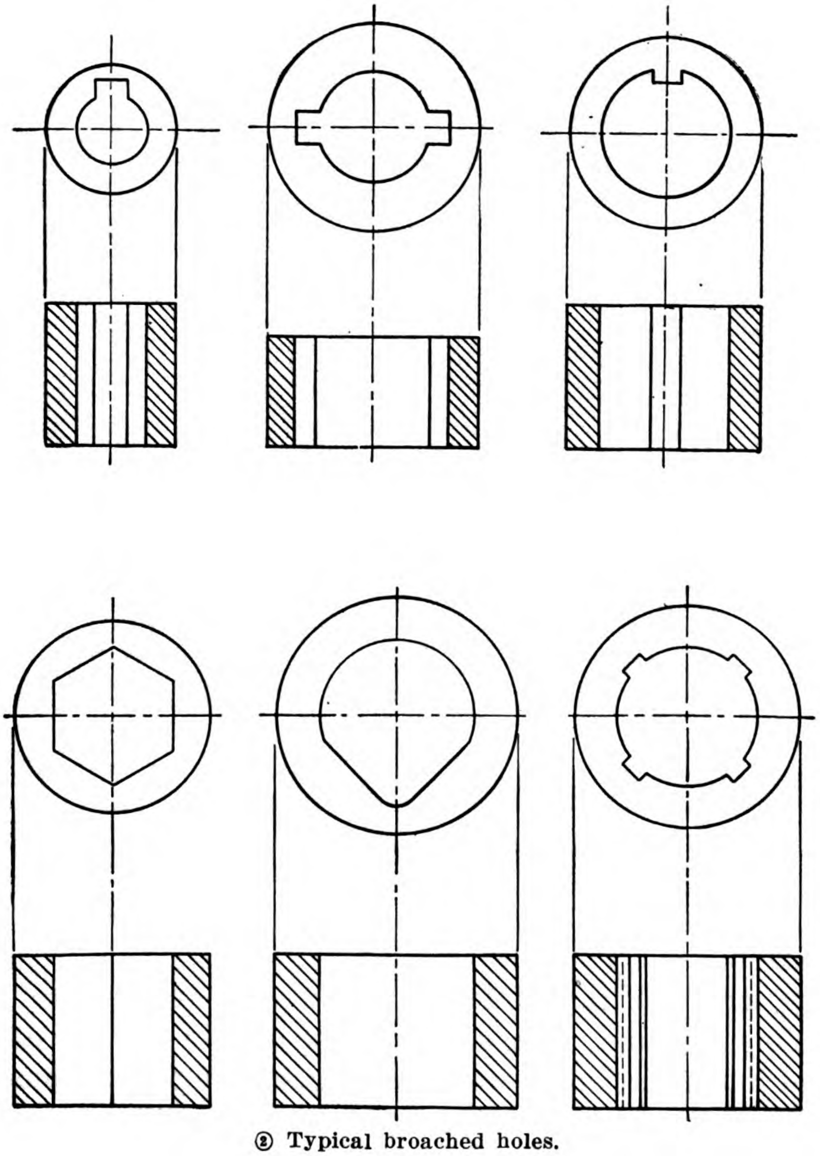
TABLE X.—*Allowable tolerances for standard splines*

Diameter of shaft (inches)	Tolerance for 4, 6, and 10 splines (inches)		
	D[1]	d[1]	W[1]
Up to 2-------	+0. 000 to −0. 001	−0. 000 to +0. 001	−0. 000 to +0. 002
2 to 3---------	+. 000 to −. 002	−. 000 to +. 002	−. 000 to +. 003
Above 3-------	+. 000 to −. 003	−. 000 to +. 003	−. 000 to +. 003
	Tolerance for 16 splines (inches)		
All diameters--	+0. 000 to −. 003	−. 000 to +. 003	−. 000 to +. 003

[1] For identification of dimensions *D*, *d* and *W*, reference should be made to figure 83.



① Broaching process.



② Typical broached holes.

FIGURE 84.—Broaching.

25. Broaching.—*a.* The process of broaching consists of pulling or pushing a toothed cutting tool across a surface or through a cored or drilled hole. The broaching tool has a series of cutting teeth which are graduated in size, each removing a small chip as the operation is performed.

b. Broaching is particularly adapted for the finishing of square or irregularly shaped holes, internal gears, splines, and keyways. Figure

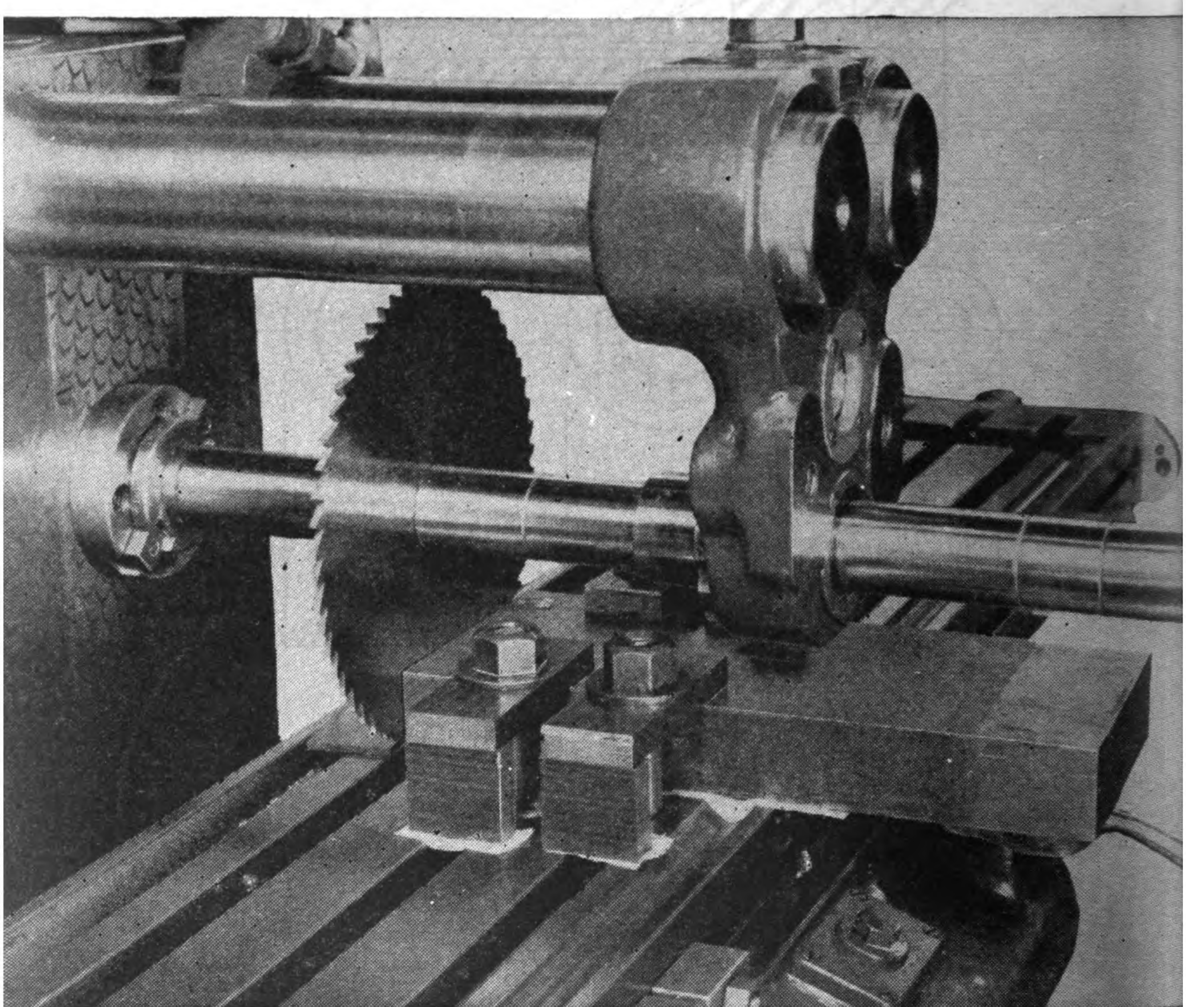


FIGURE 85.—Parting solid stock.

84 illustrates the operation as well as several shapes that may be produced by the process.

26. Sawing and parting.—Metal slitting saws are used to part stock on a milling machine. The stock may be held in any one of the ways described in the section on work holding, although care must be used to have it rigidly mounted. Figure 85 illustrates the parting of solid stock with the work being fed against the rotation of the cutter.

For greater rigidity while parting thin material such as sheet metal, the work may be clamped directly to the table with the line of cut over one of the table T-slots. In this case the work should be fed into, and with the rotation of the cutter to prevent it from being raised off the table. During the process every precaution should be taken to eliminate backlash and spring, in order to prevent climbing or gouging.

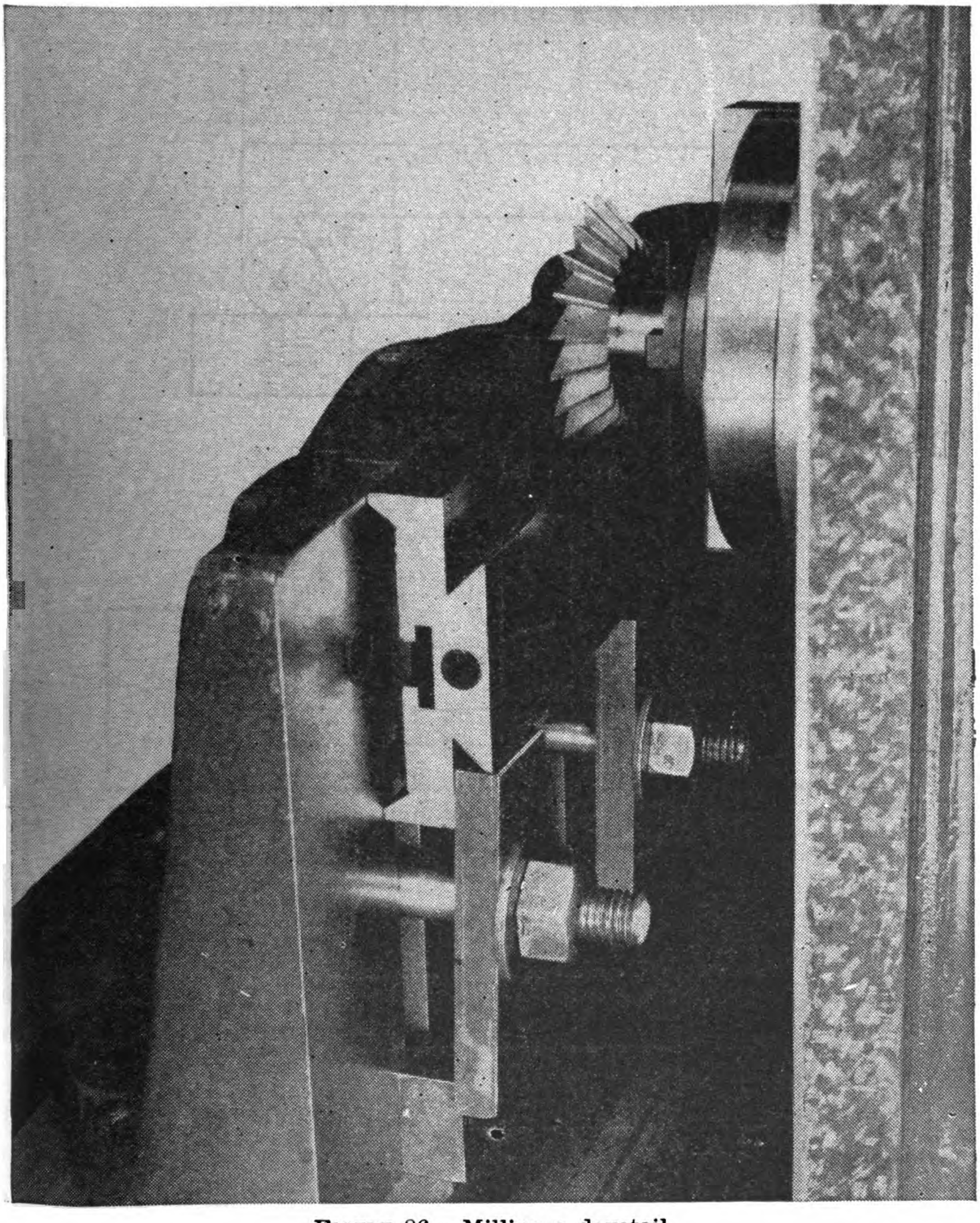
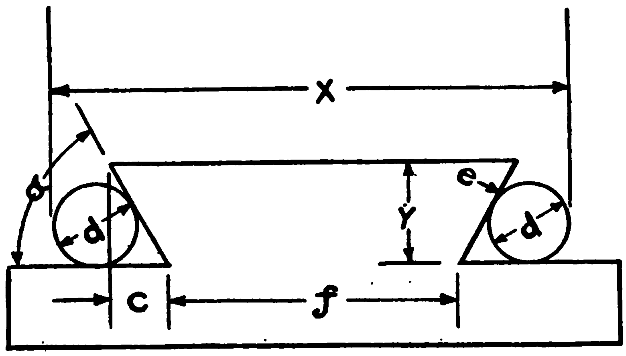


FIGURE 86.—Milling a dovetail.

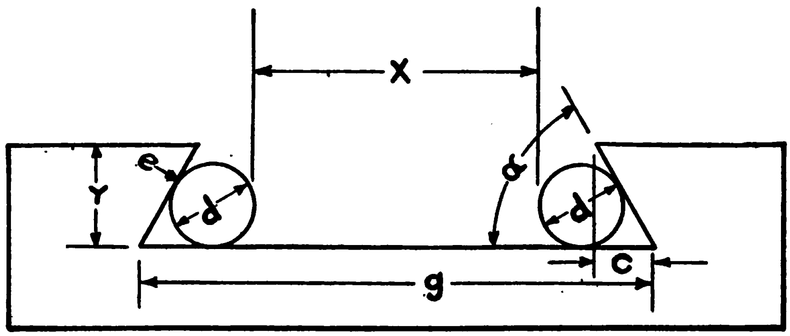
27. Dovetail milling.—*a.* Dovetails, as illustrated in figure 86, are used for connecting many machine parts and are particularly advantageous as their construction allows sliding movement, yet provides close alinement between the members. The angular sides of a dovetail may be cut on the milling machine or shaper to any desired slope, however an angle of 50°, 55°, or 60° is generally used.

b. When cutting dovetails in the milling machine, the work may be held in the vise, clamped on the table, or clamped to an angle plate as illustrated in figure 86. The tongue or groove is first roughed-out by using a side milling cutter, after which the angular sides and base are finished with an angular cutter.

c. In general practice, the dovetail is laid out on the work before the milling operation is started. To do this, the required outline should be inscribed and the line prick punched. These lines and punch marks may then be used as a guide during the cutting operation.



① Male dovetail.



② Female dovetail.

FIGURE 87.—Method of measuring dovetails.

d. Accurate measurement of the angular sides is absolutely necessary, and may be accomplished by using round rods such as drill rods or wires as shown in figure 87. These rods or wires should be of such a diameter that the point of contact, shown at *e* in the figure, is below the corner or edge of the dovetail.

(1) When measuring male dovetails the dimension *x* may be determined by adding the dimension *f* to the product of the diameter *d* and the sum of 1 plus the cotangent of ½ the dovetail angle α. Thus: $x = d\ (1 + \text{cotangent}\ \frac{1}{2}\ \alpha) + f$.

(2) When measuring female dovetails, the dimension *x* may be determined by subtracting from the width (*g*), the product of dimension

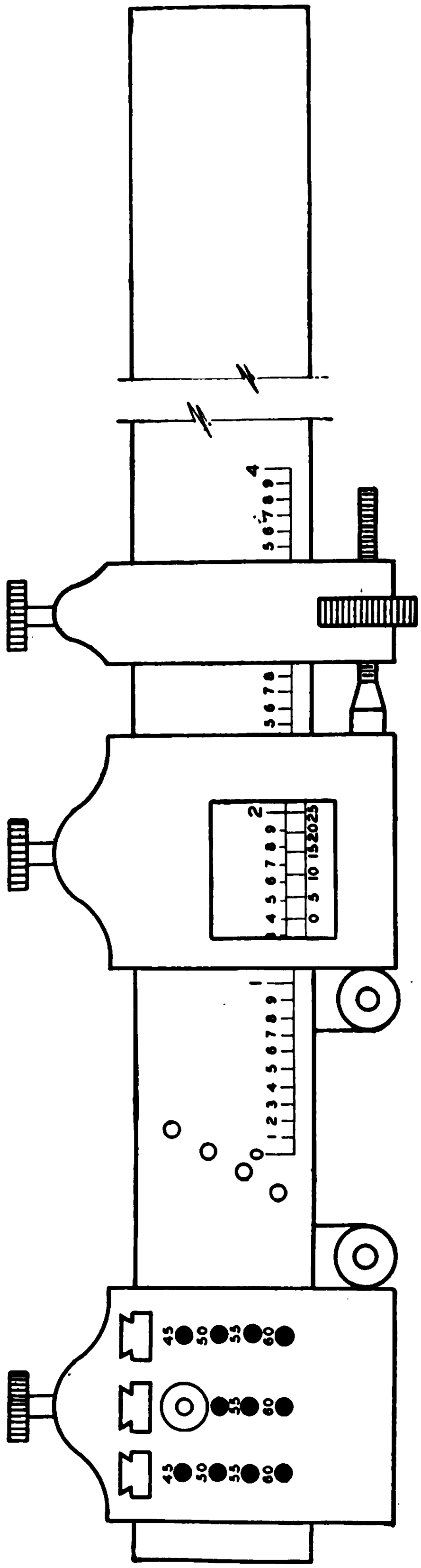


FIGURE 88.—Dovetail vernier caliper.

d and 1 plus the cotangent of ½ the angle α. Thus: $x = g - d$ $(1 + \text{cotangent } \tfrac{1}{2}\ \alpha)$.

(3) To determine the roughing size of the tongue or groove, it is necessary to calculate the dimension *c*. This is equal to the height of the tongue or groove *y*, multiplied by the cotangent of the angle α. Thus: $c = y \times \text{cotangent of angle } \alpha$.

e. Dovetails of 45°, 50° and 60° may be measured with the dovetail vernier caliper as illustrated in figure 88. This type of caliper will determine measurements in thousandths of an inch from zero to 12 inches. A taper plug locates the caliper side in relation to the required angle and direct measurement is obtained by the caliper buttons in contact with the sides of the angle.

28. Countersink milling.—*a*. Countersinks (fig. 89) are used to cut cone-shaped depressions such as screw seats and center holes. These tools are similar to reamers and may have from one to four flutes. Countersinks are usually made in diameters ranging from ⅝

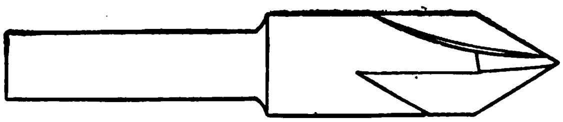


FIGURE 89.—Countersink.

to 1 inch and in various degrees of included angle, the most common being 60° and 82°.

b. When milling the flutes in a countersink, a side milling cutter is generally used. A cutter 2½ inches in diameter should be employed for fluting a ¼-inch diameter countersink, and a cutter ¼ inch larger in diameter should be used for each ⅛ inch increase of countersink size. Thus a 3-inch diameter cutter would be used to flute a ½-inch diameter countersink.

c. During the milling operation, the countersink is held in the chuck which is fastened to the index head, and the spacing of the flutes is accomplished by indexing.

29. Counterbore milling.—*a*. A counterbore (fig. 90) is a tool used to square the bottoms of holes so that fillister head screws may seat properly. The number of flutes is, in general, determined by the size of the counterbore and may vary from 3 to 5.

b. The counterbores generally used for steel have radially cut teeth, milled at a 15° helix angle, measured with respect to the center line. Counterbores for brass have straight milled teeth to prevent their digging into the soft metal.

c. The milling operation required in making a counterbore is very similar to that described for reamers. The flutes should be cut deep enough to extend below the surface of the pilot so that the body of the counterbore will have the maximum width of cutting edge. The cutter used may be of either the single or double angle type.

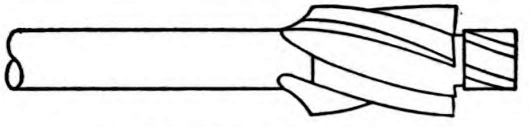


FIGURE 90.—Counterbore.

30. Drilling and boring.—*a.* The milling machine may be used effectively for drilling and boring, since accurate location of the hole may be secured by means of the feed screw graduations. The spacing of holes in a circular path, such as the holes in an index plate, may be accomplished by indexing.

b. Drills may be held in drill chucks fastened in the milling machine spindle or mounted directly in milling machine collets. Various types of boring tool holders may be used for boring on the milling machine, the boring tools being provided with either straight shanks to be held in chucks and holders, or taper shanks to fit collets. The two attachments most commonly used for boring are the fly cutter and the offset boring head, illustrated in figures 16 and 91.

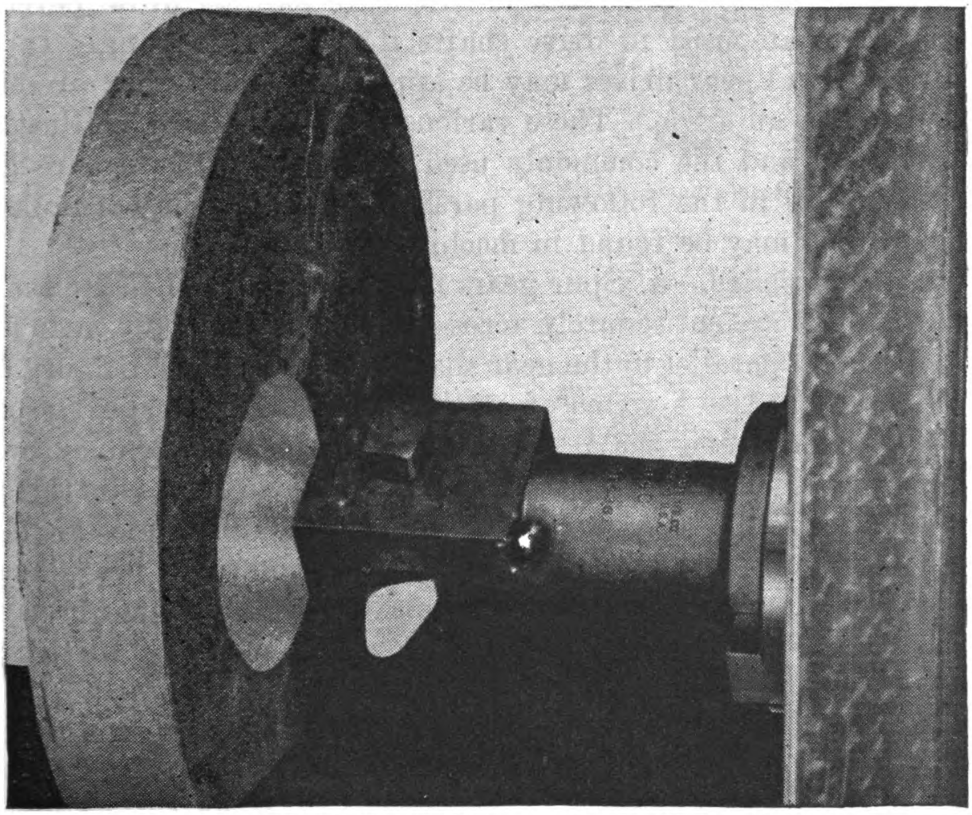


FIGURE 91.—Boring, using a fly cutter.

(1) The offset boring head has a movable holder which carries the boring bar as an integral part of the head. This holder can be offset in thousandths of an inch by turning a graduated screw, so that holes of various sizes may be bored.

(2) Both the tools used and the methods of location for boring are identical with those described in TM 1-420.

SECTION V

GEAR CALCULATIONS

31. General.—Gears are used for transmitting positive and uniform rotary motion from one shaft to another. Spur and herringbone gears are used to drive shafts that are parallel while bevel and worm gears are used to drive shafts that are at an angle to each other. Helical gear drives may be applied to shafts that are either parallel or at an angle. These various types of gears are illustrated in figure 92 and the commonly used rules and formulas are given for each type in the following paragraphs. If other formulas are desired, they may be found in machinists' handbooks.

32. Spur gears.—*a.* Spur gears may be distinguished by the fact that the teeth are cut squarely across the outer rim of the gear blank in a direction parallel to the gear shaft axis as shown in figure 92①.

b. There are two systems of cutting teeth used for spur gearing: the epicycloidal and the involute. The involute system is by far the more commonly employed and is therefore described in this text. The standard involute gear tooth has a pressure angle of 14½°; the pressure angle being the angle at which one tooth bears against the other. Involute gears having this angle are made in various standard sizes from ½ to 60 pitch, however, most cut teeth range from 4 to 20 pitch, as illustrated in figure 93. Eight milling cutters are manufactured for each pitch and are numbered from 1 to 8. These cutters are selected for the production of gears having different numbers of teeth as indicated in table XI. Gear cutters in half sizes, ranging from 2 to 8 pitch inclusive, can be obtained, if needed, for finer divisions.

c. A knowledge of gear nomenclature, rules, and other specific data is necessary in order to select the proper cutter and perform the other operations required to complete the gear. The following definitions

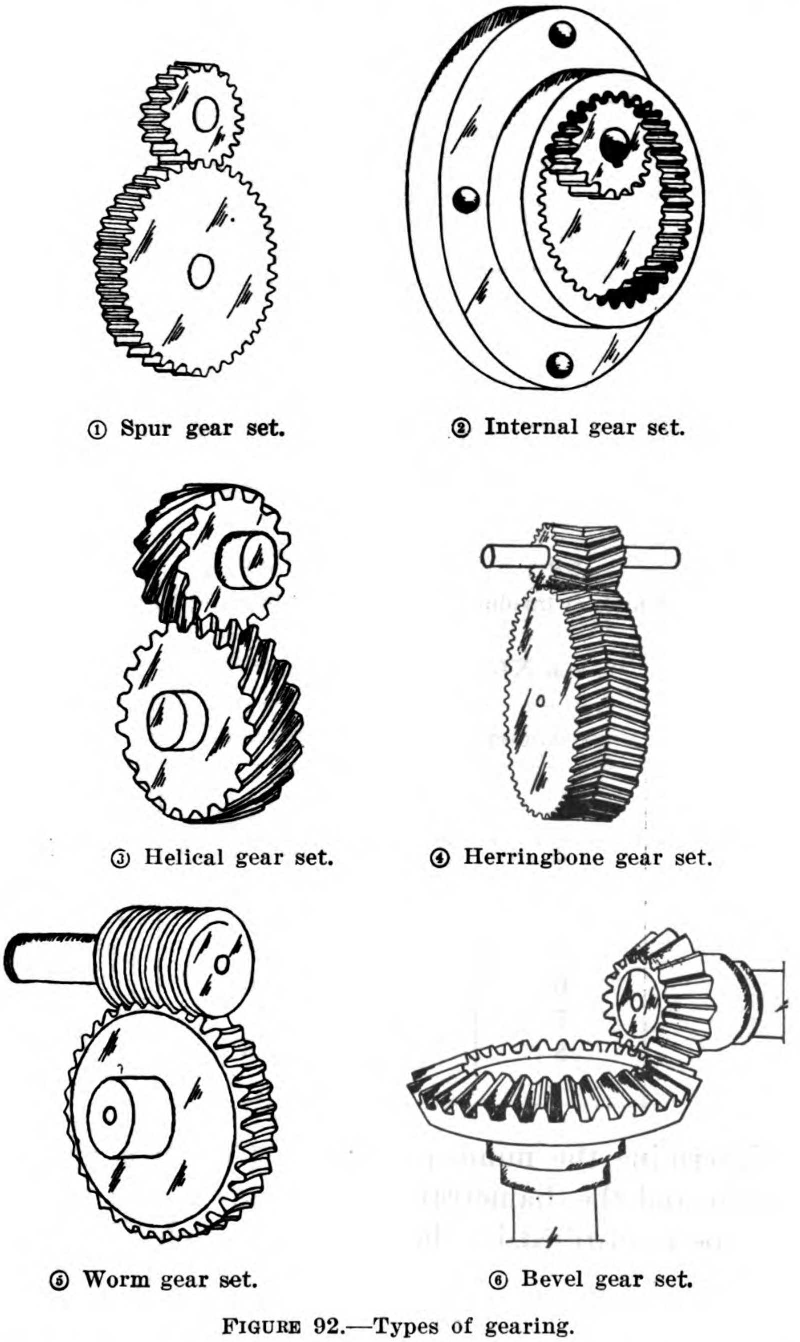


FIGURE 92.—Types of gearing.

and formulas apply to the calculations involved in cutting an involute spur gear, and the various symbols used are illustrated in figure 94.

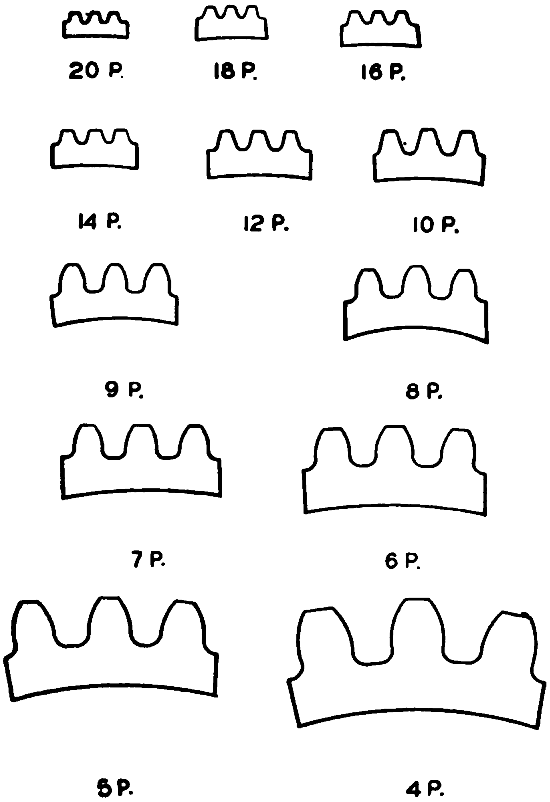


FIGURE 93.—Standard involute gear teeth having 14½° pressure angle.

TABLE XI.—*Involute gear cutters*

Cutter number	Number of gear teeth
1	From 135 to rack
2	55 to 134
3	35 to 54
4	26 to 34
5	21 to 25
6	17 to 20
7	14 to 16
8	12 to 13

(1) To determine the number of teeth (N) in a gear when the pitch diameter and the diametral pitch are given, the pitch diameter (D') should be multiplied by the diametral pitch (P).

$$N = D'P$$

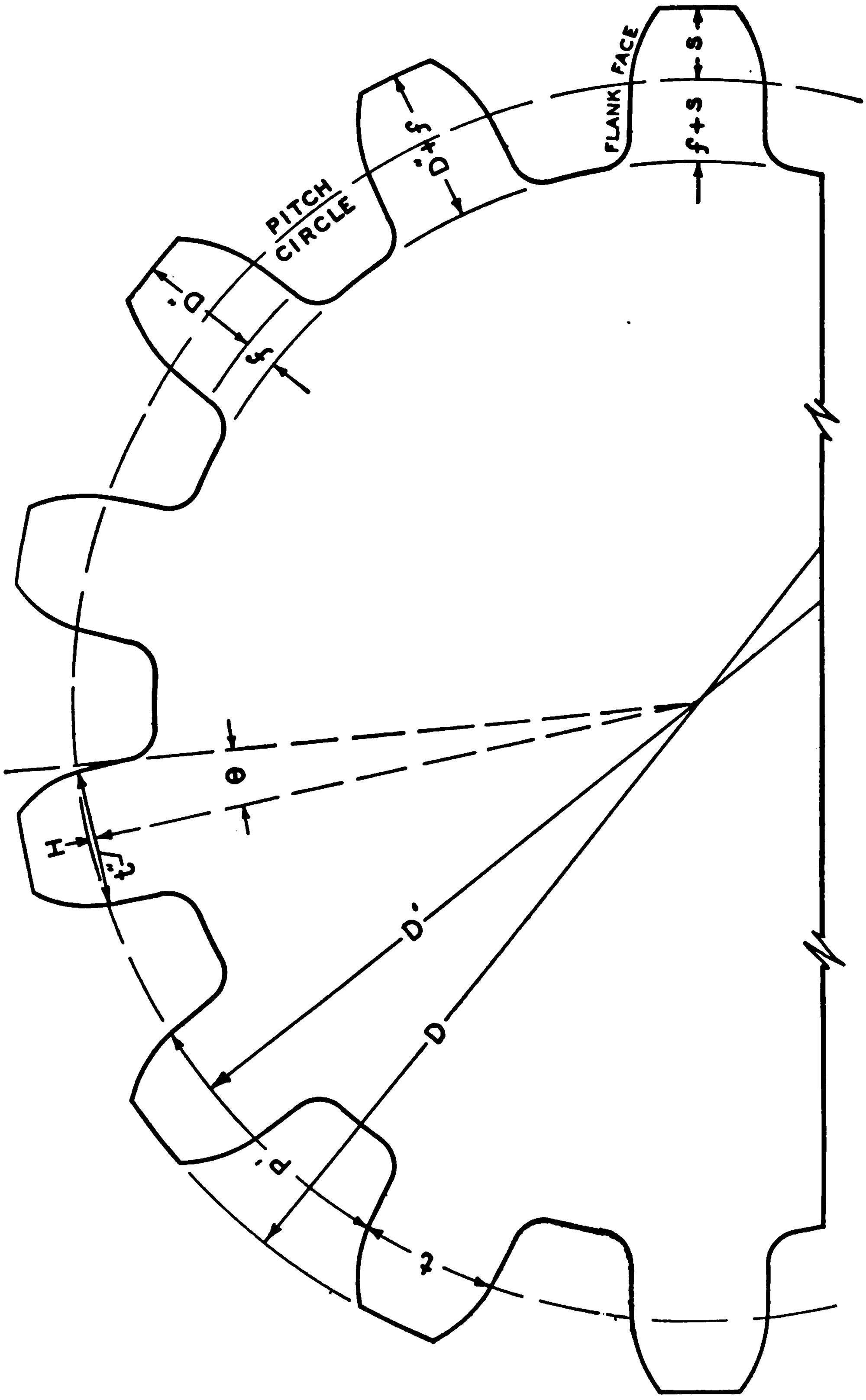


FIGURE 94.—Nomenclature for spur gearing.

(2) The outside diameter of a gear is its maximum diameter and can be determined by dividing the sum of the number of teeth (N) plus 2 by the diametral pitch (P).

$$D=\frac{N+2}{P}$$

(3) The pitch diameter (D') is the diameter of the pitch circle and can be determined by dividing the number of teeth (N) by the diametral pitch (P).

$$D'=\frac{N}{P}$$

(4) The diametral pitch (P) is the number of teeth to each inch of the pitch diameter and can be determined by dividing the number of teeth of the spur gear by its pitch diameter (D').

$$P=\frac{N}{D'}$$

(5) The circular pitch (P') is the distance between the centers of two adjacent teeth, measured on the pitch circle, and can be determined by dividing 3.1416 (pi) by the diametral pitch (P).

$$P'=\frac{3.1416}{P}$$

(6) The addendum of a gear tooth (s) is the length of the tooth measured from the pitch circle to the outside diameter. This length can be determined by dividing the number 1 by the diametral pitch (P).

$$s=\frac{1}{P}$$

(7) The dedendum ($s+f$) is the length of the gear tooth measured from the pitch circle to the whole depth line and is equal to the addendum plus the clearance. This length can be determined by dividing the constant 1.157 by the diametral pitch (P).

$$s+f=\frac{1.157}{P}$$

(8) The clearance (f) is the extra depth of space allowed between the meshing teeth and can be determined by dividing the thickness of the tooth at the pitch circle (t) by 10.

$$f=\frac{t}{10}$$

(9) The working depth (D'') is the entire length of the tooth from the outside diameter to the base of the tooth, excluding the clearance. This length can be determined by dividing the number 2 by the diametral pitch (P).

$$D''=\frac{2}{P}$$

(10) The whole depth ($D''+f$) is the working depth plus the clearance and can be determined by dividing the constant 2.157 by the diametral pitch (P).

$$D''+f=\frac{2.157}{P}$$

(11) The thickness of tooth (t) at the pitch circle is determined by dividing the circular pitch (P') by 2.

$$t=\frac{P'}{2}$$

(12) The symbol θ is a Greek letter that is frequently employed in gear formulas. It is used to designate an angle whose value is ¼ of the angle that is subtended by the circular pitch. This value can be determined by dividing 90° by the number of teeth (N).

$$\theta=\frac{90°}{N}$$

(13) In order to set the vertical slide of the vernier tooth caliper to the corrected addendum (s''), i. e., the tooth addendum (s) plus the height of arc (H), the height from the chord to the top of the tooth must be known. This length can be found by adding the height of arc (H) to the addendum (s).

$$s''=s+H$$

(14) The height of arc (H), a linear measurement, must be added to the addendum when accurate measurements of the gear teeth are required. The addendum is measured from the pitch circle. If the

vertical slide of the vernier tooth caliper is set only to the height of the addendum, there will be an error in the measuring of the gear tooth, due to the fact that the pitch line is an arc, the height of which is the distance from the chord to the bisecting point of the arc formed by the pitch line. This distance (H) can be determined by multiplying the pitch diameter (D') by the quantity ($1-\text{cosine }\theta$) and dividing the result by 2.

$$H=\frac{D'\ (1-\text{cosine }\theta)}{2}$$

(15) The chordal thickness of the tooth (t'') is used where accurate measurement of a gear tooth is desired. This thickness is the length of a chord or straight line that connects the two points that are formed where the pitch circle strikes the finished contour of the tooth. Chordal thickness is a linear measurement and can be found by multiplying the pitch diameter (D') by the sine of angle θ.

$$t''=D'\times\text{sine }\theta$$

(16) When cutting gears, it is often necessary to know the distance between the centers of the gear shafts. This distance can be determined by dividing the sum of the number of teeth in the gears (N_g+N_p) by the sum of their diametral pitches ($2P$).

$$\text{Center distance}=\frac{N_g+N_p}{2P}$$

(17) If the center distance between the shafts of a gear and a pinion is required, it may be determined if the pitch diameter (D') of both the gear and the pinion is known. The distance between centers is the sum of the pitch diameter of the gear (D'_g) plus the pitch diameter of the pinion (D'_p), divided by 2.

$$\text{Center distance}=\frac{D'_g+D'_p}{2}$$

(18) The linear pitch (P'), used in rack measurement, is equal to the circular pitch (P') of the gear meshing into the rack.

d. The following procedure is given as an example in the calculation and cutting of a spur gear:

(1) Assume that it is required to mill 40 teeth in a spur gear blank which has a pitch diameter of 3.3334 inches.

(2) Make the necessary calculations, using the above listed formulas.

$$\text{Diametral pitch } (P)=\frac{N}{D'}=\frac{40}{3.3334}=12$$

$$\text{Circular pitch } (P')=\frac{3.1416}{P}=\frac{3.1416}{12}=0.2618 \text{ inch}$$

$$\text{Addendum } (s)=\frac{1}{P}=\frac{1}{12}=0.0833 \text{ inch}$$

$$\text{Thickness of tooth } (t)=\frac{P'}{2}=\frac{0.2618}{2}=0.1309 \text{ inch}$$

$$\text{Whole depth of tooth } (D''+f)=\frac{2.157}{P}=\frac{2.157}{12}=0.1798 \text{ inch}$$

Number of cutter (table XI) = 3

Number of turns to index for each tooth = 1

(3) Fasten the index centers to the milling machine table and aline them, if necessary. When using the universal milling machine, the table should be set at right angles to the cutter arbor so that the tooth space cut will be parallel to the axis of the gear.

(4) Secure the gear blank to the mandrel. At this point, it is important to see that the mandrel runs true so that all teeth cut upon the blank have the same relationship to the axis.

(5) Adjust the cutter centrally with the axis of the gear blank. To do this proceed as follows:

(*a*) Set a surface gage to the same height as the centers and inscribe a line across the peripheral surface of the gear blank.

(*b*) Index the blank 10 turns or one-fourth of a revolution to bring the line to top-center.

(*c*) Adjust the table to a position which places the line directly under and in the center of the cutter.

(*d*) With the cutter revolving, raise the gear blank until tool marks are left on its periphery, then stop the cutter and lower the blank sufficiently to examine the tool mark and inscribed line.

(*e*) If the line is not in the center of the tool mark, move the table transversely to bring the line directly under the center of the cutter, completing the adjustment.

(*f*) A less accurate method of accomplishing this adjustment is a visual alinement of either the headstock or tailstock center with the center of the cutter.

(6) Regulate the depth of cut by adjusting the height of the milling machine knee. With the cutter revolving, the knee is raised until the cutter just touches the blank. The graduated dial on the vertical feed is then locked and used as a guide in determining the required tooth space depth. The blank is moved from under the cutter by turning the longitudinal feed and the depth of cut set by raising the vertical feed the required number of thousandths of an inch.

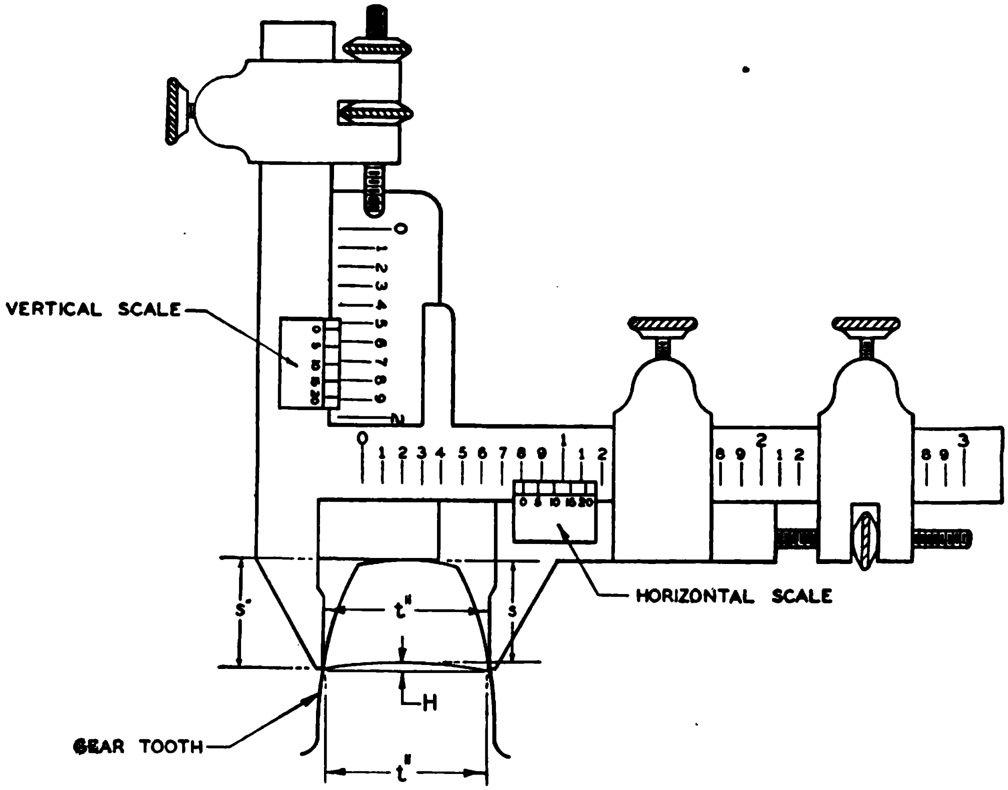


FIGURE 95.—Measuring gear teeth with a vernier caliper.

(7) Check the size of the tooth by cutting two tooth spaces into the face of the blank to a depth sufficient to produce the full form of the tooth. The tooth thus produced may then be measured and compared to the standard tooth form. Gear teeth are measured for accuracy by using the gear tooth vernier caliper (fig. 95). The vertical slide is adjusted to the height of the addendum and the jaw is adjusted to the thickness of the tooth. If, after checking the vernier scale it is found that the tooth is too thick, it will be necessary to raise the work into the

cutter and if the tooth is too narrow, the work must be lowered. For a more accurate check on gear teeth, it is necessary to work to chordal figures. These figures may be obtained by determining the chordal thickness (t'') and the corrected addendum (s'').

(8) Cut all the tooth spaces by indexing the blank. The method of indexing gear blanks is identical to that of indexing other circular work.

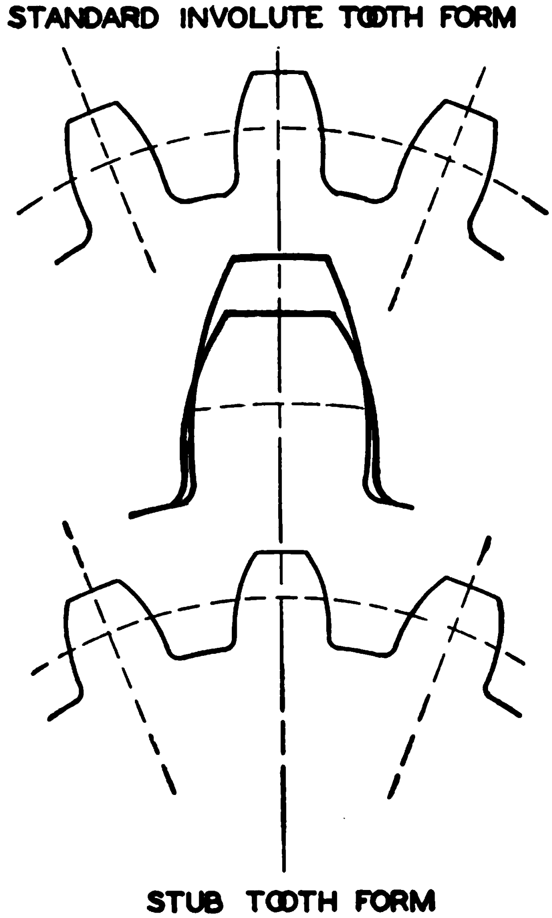


FIGURE 96.—Comparison of stub and involute gear teeth.

33. Stub tooth gears.—*a.* Stub involute tooth gears are largely used in automotive drives because of their strength. This type of gear tooth has a 20° pressure angle and is short and thick, as the name implies. The stub gear tooth is compared to the standard involute form in figure 96. Three systems of stub tooth gearing are in general use; they are the Nuttall, the Fellows, and the American Standards Association.

(1) The Nuttall system of stub tooth gearing bases the tooth dimensions directly upon the circular pitch; the addendum being made ¼ of the circular pitch, and the dedendum $\frac{3}{10}$ of the circular pitch.

(2) The American Standards Association bases the tooth dimensions upon a given set of formulas; the total depth of tooth being 1.8 divided by the diametral pitch, the addendum, 0.8 divided by the diametral pitch, and the basic thickness of the tooth, 1.5708 divided by the diametral pitch.

(3) The Fellows system of stub tooth gearing bases the tooth dimensions on two diametral pitches. For example, the gear tooth may be designated as a $^{10}/_{12}$ pitch. Referring to this fraction, the numerator equals the pitch that determines the thickness and number of teeth and the denominator equals the pitch that determines the depth of the teeth. The following formulas are used in calculating dimensions for the Fellows system of stub tooth gearing:

(*a*) The pitch diameter (D') is determined by dividing the number of teeth (N) by the numerator pitch.

$$D'=\frac{N}{\text{numerator pitch}}$$

(*b*) The addendum (s) is determined by dividing the number one by the denominator pitch.

$$s=\frac{1}{\text{denominator pitch}}$$

(*c*) The outside diameter (D) of the gear blank equals the sum of the pitch diameter (D') and two times the quotient of 1 divided by the denominator pitch.

$$D=D'+\left(2\times\frac{1}{\text{denominator pitch}}\right)$$

(*d*) The dedendum is determined by dividing the number 1 by the denominator pitch.

$$\text{Dedendum}=\frac{1}{\text{denominator pitch}}$$

(*e*) The tooth clearance (f) is determined by dividing the addendum (s) by the number 4.

$$f=\frac{s}{4}$$

b. After the stub tooth calculations have been made according to one of the above systems, the proper stub tooth cutter should be selected according to the diametral pitch. The milling operation for cutting stub tooth gears is the same as for milling standard involute teeth.

34. Internal gears.—*a*. Internal gears may be considered as circular metal bands having teeth on their inside surfaces. These gears as shown in figure 92② are especially adapted for use in propeller shaft speed reductions because of their compactness. This compactness or space saving feature is due to the fact that one gear runs within another. The relative position of the gears causes their pitch lines to bend in the same direction, enabling more teeth to be in contact simultaneously, thereby producing smooth action and great strength.

b. The method of determining the various sizes for internal gearing is practically the same as for the spur gear, except that in the calculation of the center distance, the difference between the pitch radii is used instead of their sum. In designing internal gears, care

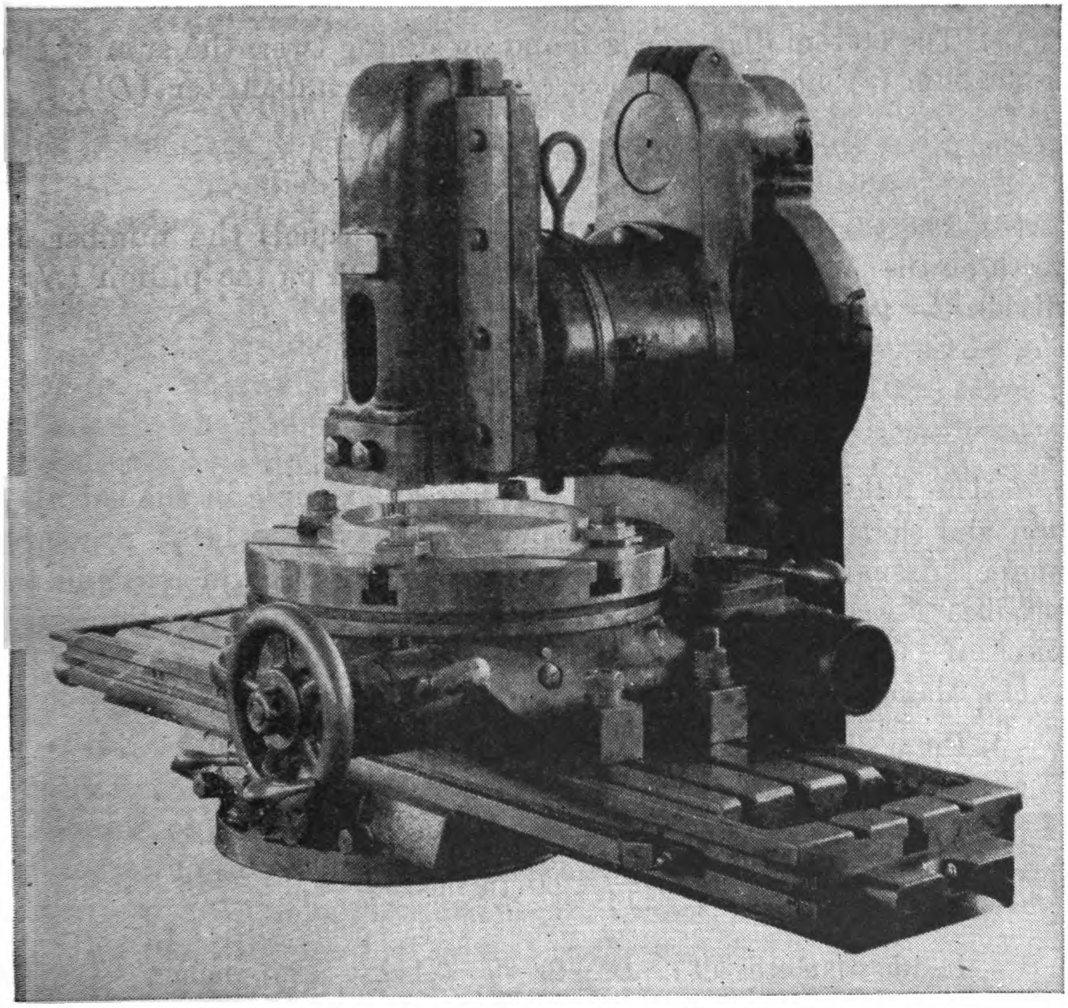


FIGURE 97.—Cutting an internal gear.

must be taken to avoid interference which may occur when the inside diameter of the gear and the outside diameter of the pinion are too closely related in size. Figure 97 illustrates the cutting of an internal gear, using the circular and slotting attachments.

c. The calculations involved in the cutting of internal spur gears are the same as those required for external gears with the exception and addition of the following formulas:

(1) The pitch diameter (D') is found by adding the sum of two addenda ($2s$) to the inside diameter of the gear (I).

$$D'=2s+I$$

(2) The inside diameter of the gear (I) is, therefore, equal to the pitch diameter (D') less the sum of two addenda ($2s$).

$$I=D'-2s$$

(3) The bottom diameter is found by adding twice the sum of the addendum (s) and the clearance (f) to the pitch diameter (D').

$$\text{Bottom diameter}=D'+2(s+f)$$

(4) The center distance of the gears (C) equals the number of teeth on the gear (Ng) less the number of teeth on the pinion (Np) divided by twice the diametral pitch ($2P$).

$$C=\frac{Ng-Np}{2P}$$

d. The following procedure is given as an example in the calculation and slotting of an internal spur gear, having a 14½° pressure angle. Assume that it is required to slot 126 teeth in a blank to produce a gear with a pitch diameter of 9 inches and a diametral pitch of 14.

(1) Make the necessary calculations as follows:

Pitch diameter (D') = 9 inches
Diametral pitch (P) = 14

$$\text{Addendum } (s)=\frac{1}{P}=\frac{1}{14}=0.0714 \text{ inch}$$

$$\text{Inside diameter } (I)=D'-2s=9-0.1428=8.857 \text{ inches}$$

$$\text{Circular pitch } (P')=\frac{3.1416}{P}=\frac{3.1416}{14}=0.224 \text{ inch}$$

$$\text{Thickness of tooth } (t)=\frac{P'}{2}=\frac{0.224}{2}=0.112 \text{ inch}$$

$$\text{Clearance } (f) = \frac{t}{10} = \frac{.112}{10} = 0.0112 \text{ inch}$$

$$\text{Bottom diameter} = D' + 2(s+f) = 9 + 2(0.0714 + 0.0112) = 9.165 \text{ inches}$$

$$\text{Whole depth } (D'' + f) = \frac{2.157}{P} = \frac{2.157}{14} = 0.154 \text{ inch}$$

(2) Aline and clamp the gear blank on the circular attachment, o that the axis of the blank coincides with the axis of the circular ttachment. Strap clamps are usually used to hold the blank, which s mounted on raising blocks to give the tool proper clearance. To ssist in alining the gear, a dial test indicator should be fastened on o the slotting attachment. To do this, the contact point of the dial ndicator is made to touch the inside of the gear blank, and the gear lank is revolved by using the rotary action of the circular attachnent. Any deviation from proper alinement, as registered by the ial indicator, should be corrected by lightly tapping the gear blank. Vork of small diameter may be held on the index head, eliminating he necessity of the circular attachment.

(3) By moving the milling machine table transversely, scribe a adial line completely across the center of the top face of the blank ith a scriber held in the slotting attachment. Revolve the gear blank 80° with the circular attachment handwheel and repeat the process f scribing the line. Should it be found that the two inscribed lines lo not coincide, the table of the milling machine should be adjusted ongitudinally and the process of revolving the blank repeated until he lines do coincide. The graduated dial on the longitudinal feed s then locked and used as a guide, to inscribe two lines parallel to he center line of the gear blank, and spaced an amount equal to half he tooth width on either side of the center line. These lines assist n the alinement of the slotting tool and when inscribed, the graduated dial on the longitudinal feed is used to adjust the milling nachine table to the position held when the center line was drawn. n this position, the longitudinal feed is locked.

(4) Fasten a slotting tool ground to the shape of a No. 1 involute utter of the required pitch to the slotting attachment. The cutter nust be adjusted to its proper alinement with the gear blank by neasurements taken from the inscribed lines discussed in the oregoing paragraph.

(5) After moving the work with the transverse feed until it just ouches the cutter, lock the graduated dial so that it may be used

as a guide, and cut the required tooth space. The transverse fee stop is then locked and the work moved away from the cutter wit the transverse handwheel. At this point, by means of the circula attachment, the blank should be indexed and an adjacent tooth spac cut. The tooth so formed should be measured and the transvers stop, which regulates the tooth depth, adjusted to produce a toot of the proper size. This indexing and cutting process is repeate until all of the teeth have been cut.

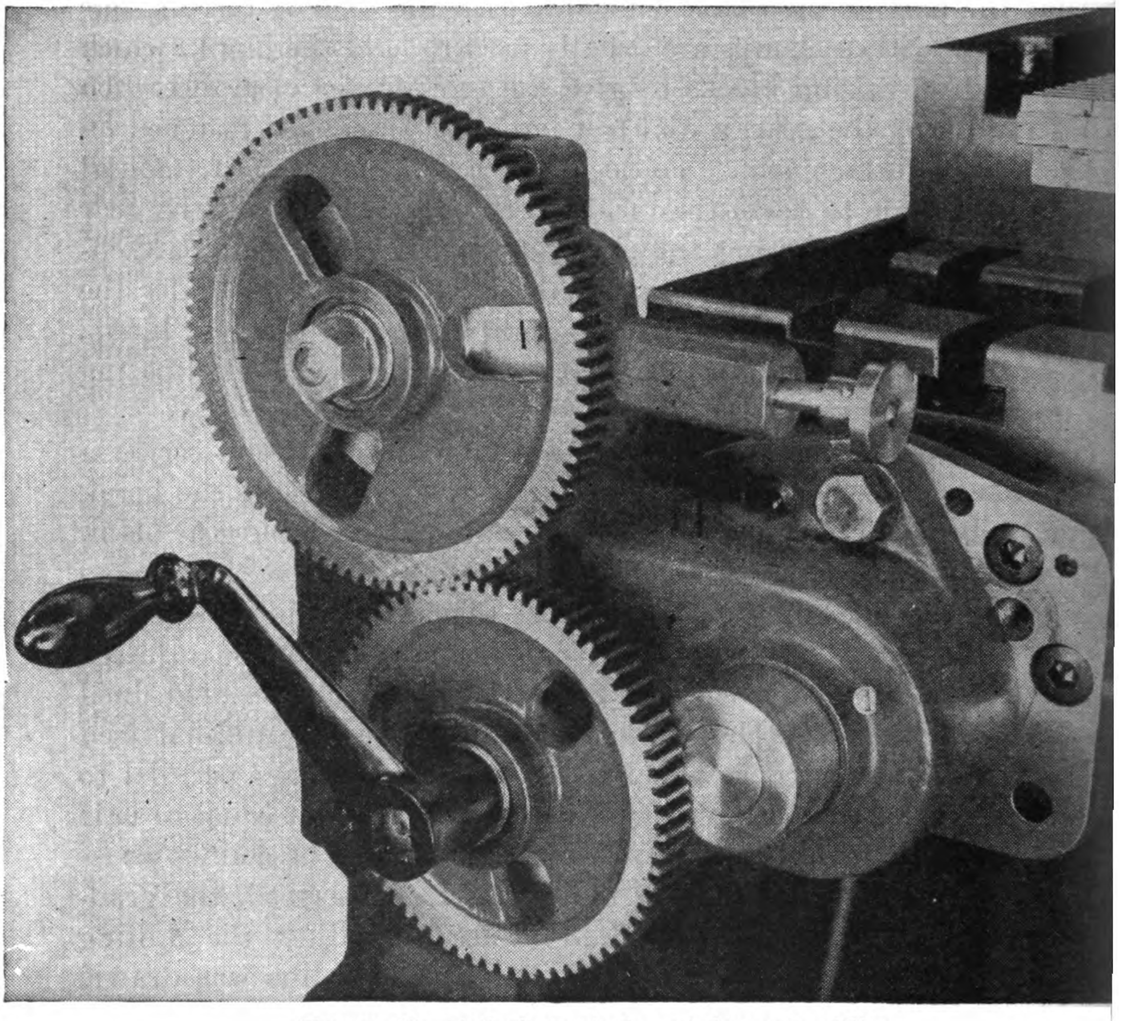


FIGURE 98.—Indexing attachment for rack milling.

(6) The vertical shaper may also be used for cutting interna gears, by following the operations discussed above.

35. Racks.—*a.* A rack such as shown in figure 15, is a straight ba having teeth to mesh with a spur gear. When operated with a spu gear, the rack produces a reciprocating action as in the longitudina feed of a lathe carriage.

b. When cutting racks on a milling machine, any one of three methods may be employed.

(1) Racks may be cut by using the rack milling and indexing attachments. The bar upon which the teeth are to be cut is fastened in the attachment vise and the teeth are indexed by using the indexing attachment as shown in figures 15 and 98.

(2) For racks having few teeth, the cutter may be held on a common arbor with the work clamped or held in a vise, parallel to the arbor axis. In this case, the tooth spaces are indexed by hand, using the transverse feed of the milling machine.

(3) When the rack milling attachment is not available, and the cutter is large enough in diameter to eliminate interference with the universal head, long racks may be cut by clamping the bar to the milling machine table at 90° to the milling machine spindle. The cutter should be mounted on an arbor, held in the universal milling attachment, with the arbor axis parallel to the bar. The tooth spaces are then indexed by hand, using the longitudinal feed of the milling machine. When determining the dimensions of the rack teeth, the linear pitch of the rack is made equal to the circular pitch of the gear that meshes into it. The diametral pitch, whole depth of tooth, thickness of tooth and addendum are also the same as the corresponding measurements of the gear with which it is to mesh. In all cases, a No. 1 involute gear cutter should be used.

36. Helical gears.—*a*. Helical gears as shown in figure 92③ are gears which have teeth cut across the outer rim of the gear blank at an angle to their axis, similar to the thread of a screw. Helical gears operate smoothly and have great strength because of the sliding action of the teeth and the greater number of teeth that are in contact at any one time. These gears may have either a right- or a left-hand helix.

b. Important factors to be considered when cutting helical gears are:

(1) The teeth of helical gears must have opposite helix angles when their shaft axes are parallel, so that they may mesh.

(2) The teeth of helical gears must have the same helix angle when the axes of their shafts are at right angles.

(3) The helix angle is dependent upon the design of the gear and the relative position of the shafts.

(4) The universal milling machine can be used to cut gears up to a 45° helix angle by swiveling the table and mounting the cutter in the usual manner. Should the helix angle be greater than that which

the table will accommodate, a vertical milling attachment is used a
the cutting angle adjustment is made with the attachment.

c. The following is an explanation of the symbols and formu
involved in calculating and cutting helical gears. The various symb
may be identified by referring to figure 99.

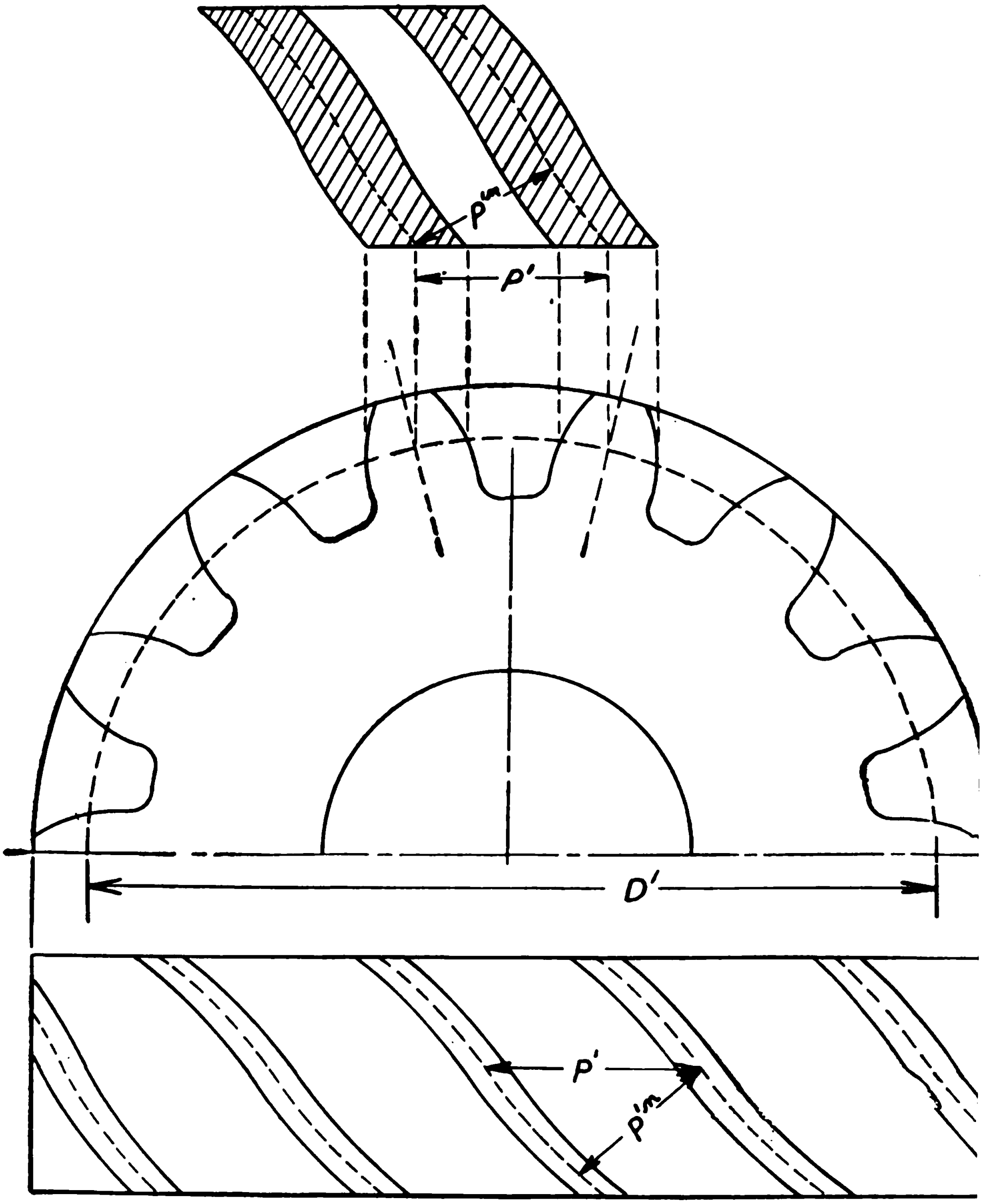


FIGURE 99.—Normal pitch diagram for a helical gear.

(1) The normal circular pitch (P'^n) is the shortest distance betw
the centers of two adjacent teeth measured along the pitch surf
and equals the circumferential circular pitch (P') multiplied by
cosine of the angle formed between the teeth and the axis of the g

$$P'^n = P' \times \text{cosine of angle of teeth with axis}$$

(2) In selecting the cutter for cutting helical gear teeth, it is not possible to use a cutter of the same size and number as is used for like teeth in spur gear cutting. Such a cutter which has a thickness at the pitch line equal to one-half the circular pitch would cut tooth spaces too wide, thus producing thin teeth. It is therefore, necessary to select the cutter according to the normal diametral pitch (P^n), which can be determined by dividing 3.1416 (pi) by the normal circular pitch (P'^n).

$$P^n = \frac{3.1416}{P'^n}$$

(3) The number of teeth (T) for which a helical gear cutter is selected may be determined by dividing the number of teeth in the helical gear (N) by the product of the square of the cosine multiplied by the sine of the helix angle.

$$T = \frac{N}{(\text{cosine of angle})^2 \times \text{sine of helix angle}}$$

(4) The exact lead of the helix (L_1) on the pitch surface is determined by dividing the tangent of the tooth angle into the product of the number of teeth (N) and the circumferential circular pitch (P').

$$L_1 = \frac{NP'}{\text{tangent of tooth angle}}$$

(5) The approximate lead is the lead for which interchangeable gears are available for use with the standard universal index centers. In cutting helixes the operator must accommodate the exact lead to the approximate lead. The differences in the two are usually very small and can be compensated for by simply cutting the tooth space slightly larger. To determine the approximate lead of the helix (L_2) that may be cut by gears usually furnished with index centers, the product of the number of teeth in the driven gears must be multiplied by 10 and divided by the product of the number of teeth in the driver gears.

$$L_2 = \frac{10 \times \text{product of number of teeth in driven gears}}{\text{product of number of teeth in driver gears}}$$

(6) The circular pitch (P') may be determined by dividing the product of the pitch diameter and 3.1416 (pi) by the number of teeth (N).

$$P' = \frac{D' \times 3.1416}{N}$$

(7) The pitch diameter (D') of a helical gear may be determined by dividing the product of the circular pitch (P') and the number of teeth (N) by 3.1416 (pi).

$$D'=\frac{P'N}{3.1416}$$

(8) The addendum (s) may be determined by dividing the normal circular pitch (P'^n) by 3.1416 (pi).

$$s=\frac{P'^n}{3.1416}$$

(9) The outside diameter (D) may be found by adding the pitch diameter (D') to twice the addendum ($2s$).

$$D=D'+2s$$

(10) The thickness of tooth (t) may be determined by dividing the normal circular pitch (P'^n) by 2.

$$t=\frac{P'^n}{2}$$

(11) The whole depth of tooth ($D''+f$) is equal to two addenda ($2s$) plus one-tenth the thickness of the tooth $\left(\frac{t}{10}\right)$

$$D''+f=2s+\frac{t}{10}$$

(12) The Greek letter α is used to indicate the angle of the teeth with the axis, while the Greek letter γ is used to indicate the angle of the shaft axes. Gamma is equal to the sum of the helix angle of two mating gears.

$$\gamma=\alpha 1+\alpha 2$$

d. The following procedure is given as an example in the calculations and cutting of a helical gear. Assume that it is required to mill the teeth in a 21-tooth helical gear, having a pitch diameter of 3.712 inches and a helix angle of 45°.

(1) Make the necessary calculations as follows:

Number of teeth (N) = 21

Pitch diameter (D') = 3.712 inches

Circular pitch $(P')=\frac{D'\times 3.1416}{N}=\frac{3.712\times 3.1416}{21}=0.5553$ inch

Normal circular pitch $(P'^n) = P' \times$ cosine of tooth angle
$= 0.5553 \times 0.70711 = 0.3927$ inch

Addendum $(s) = \frac{P'^n}{3.1416} = \frac{0.3927}{3.1416} = 0.125$ inch

Outside diameter $(D) = D' + 2s = 3.712 + 0.250 = 3.962$ inches

Normal diametral pitch (pitch of cutter)

$$= (P^n) = \frac{3.1416}{P'^n} = \frac{3.1416}{0.3927} = 8$$

Thickness of tooth $(t) = \frac{P'^n}{2} = \frac{0.3927}{2} = 0.1963$ inch

Whole depth $(D'' + f) = 2s + \frac{t}{10} = 0.250 + \frac{0.1963}{10} = 0.2696$ inch

Number of teeth for which cutter must be selected (T)

$$= \frac{N}{(\text{cosine of angle})^2 \times \text{sine of helix angle}}$$

$$= \frac{21}{(0.70711)^2 \times 0.70711} = 59$$

Number of cutter (table XI) = No. 2

Exact lead $(L_1) = \frac{NP'}{\text{tangent of tooth angle}} = \frac{21 \times .5553}{1}$

$= 11.661$ inches

Approximate lead $(L_2) = \frac{10 \times \text{product of driven gears}}{\text{product of driver gears}}$

$$= \frac{10 \times 64 \times 28}{32 \times 48} = 11.666 \text{ inches}$$

Where the following gear selection is used:

Gear on worm	64 teeth (driven)
First gear on stud	32 teeth (driver)
Second gear on stud	28 teeth (driven)
Gear on screw	48 teeth (driver)

(2) Fasten the universal index centers to the milling machine table d aline them if necessary.

(3) Set the universal milling machine table at right angles to the ter arbor, secure No. 2, 8-pitch involute gear cutter on the arbor and ne the cutter as explained in the paragraph on "helical milling."

(4) Press the gear blank on a mandrel and mount it on the spiral lex centers. The arbor must be secured to and driven by the head-ck spindle. Due to the rotary motion of the gear blank while being , helical gears are more liable to slippage in cutting than are spur rs. For this reason, it is necessary that the gear blank be pressed htly upon the mandrel. Small diameter gear blanks held on lathe

mandrels, may be secured to the spindle by the use of a dog; howeve the dog must be far enough from the blank to eliminate any cutt interference. Large diameter gear blanks should be pressed on tap shank arbors that are held directly in the headstock spindle, and f extremely heavy work this type of arbor may be drawn into the spind with a threaded rod.

(5) Connect the index head to the lead screw of the machine b means of the series of gears selected.

(6) Arrange the index head to index the number of teeth requir and unlock the index plate to allow it to revolve.

(7) Set the milling machine table at the proper angle.

(8) The depth of cut, measuring of the tooth, setting of the vertic stops, and the indexing of the gear blank are the same as those oper tions for spur gearing. The various points discussed in the cutting helixes also apply to helical gear cutting. An important factor th should be remembered in cutting helical gear teeth is that the cutt should be stopped after cutting each tooth space, and the table r turned by hand with the cutter positioned, so that its teeth will n scrape the sides and bottom of the tooth space.

37. Herringbone gears.—Herringbone gears, shown in figu 92④, perform much the same function as spur gears. These gea which are similar to helical gears, have all the advantages of the helic gear plus the additional advantage of the neutralization of end thrus The simplest way to manufacture a herringbone gear is to cut two hel cal gears of the same diametral pitch and number of teeth, one havin a right-hand helix, and the other a left-hand helix. These two gea are then fastened together to operate as a single gear. Herringbo gears usually have a helix angle of 23° and a face width of from 6 12 times the circular pitch. The tooth is an involute form having pressure angle of 20°.

38. Worm gears.—*a.* Worm gears provide a high ratio of spe reduction within a very small space. They are self locking and ve smooth in action.

b. As shown in figure 92⑤, the worm gear set combines a screw worm with a worm wheel, having helical cut teeth and mounted on shaft at right angles to that of the worm. The worm is generall machined (including the cutting of the screw thread) on the lath while the worm wheel blank is turned on the lathe, and the teeth a cut on the milling machine.

c. The following is an explanation of the symbols and formulas in volved in calculating and cutting single and double threaded worm and worm wheels. The various symbols employed are illustrated in figure 100.

(1) The number of teeth (N) in the worm wheel is determined by the ratio of the gearing and the center distance desired.

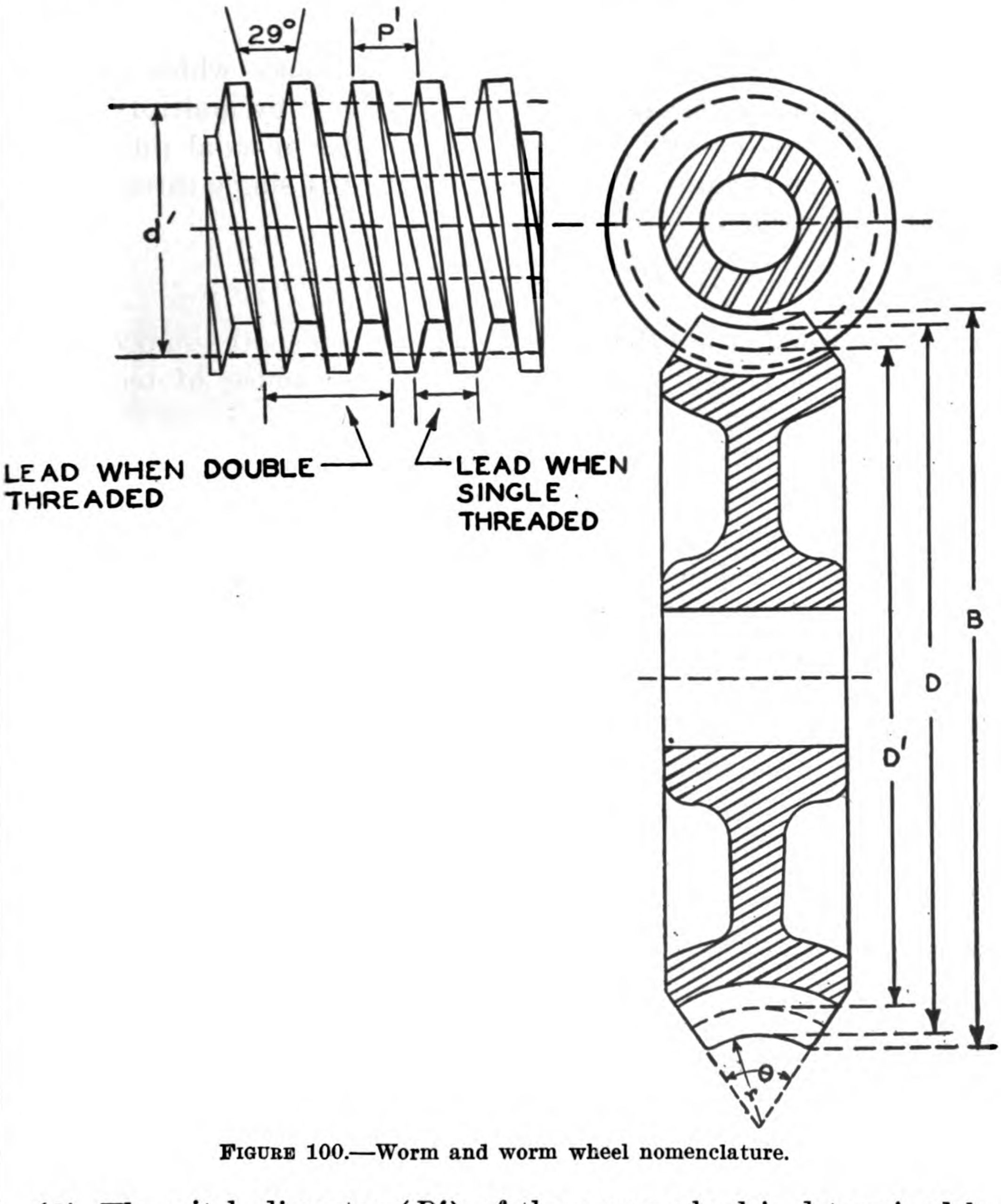


FIGURE 100.—Worm and worm wheel nomenclature.

(2) The pitch diameter (D') of the worm wheel is determined by dividing the product of the number of teeth in the gear (N) and the circular or axial pitch (P') by 3.1416 (pi).

$$D'=\frac{NP'}{3.1416}$$

(3) The circular pitch for the worm wheel or the axial pitch for the worm (P') is determined by dividing the number of teeth (N) into the product of 3.1416 (pi) and the pitch diameter (D').

$$P' = \frac{3.1416 \times D'}{N}$$

(4) The lead (L) of the worm or the distance which any one thread advances in one revolution is determined by multiplying the number of threads in the worm by the circular or axial pitch (P'). This number of threads on the worm will be 1 if single threaded and 2 if double threaded.

$$L = P' \times (\text{number of threads})$$

(5) The worm wheel throat diameter (D) equals the sum of twice the addendum ($2s$) and the quotient of the number of teeth (N) divided by the diametral pitch (P).

$$D = \frac{N}{P} + 2s$$

(6) The radius of the worm wheel throat (r) may be determined by subtracting twice the addendum of the worm wheel ($2s$) from half the outside diameter of the worm.

$$r = \frac{\text{outside diameter of worm}}{2} - 2s \text{ (worm wheel)}$$

(7) The outside diameter of the worm wheel blank (B) is not an important dimension because of the small land usually allowed on its periphery. Approximate measurements may be determined by taking the sum of the worm wheel pitch diameter (D') and three times the addendum ($3s$).

$$B = D' + 3s$$

(8) The center distances for worm gearing (C) is equal to half the sum of the pitch diameters of the worm wheel (D') and of the worm (d').

$$C = \frac{D' + d'}{2}$$

(9) The pitch diameter of the worm (d') may be determined by subtracting the pitch diameter of the worm wheel (D') from twice the center distance ($2C$).

$$d' = 2C - D'.$$

(10) The gashing angle at which the milling machine table should be set for the gashing operation on the worm wheel is the angle whose tangent is determined by dividing the lead of the worm (L) by the product of 3.1416 (pi) and the pitch diameter of the worm (d').

$$\text{Tangent of angle} = \frac{L}{3.1416 \times d'}$$

(11) When a worm wheel gashing cutter such as shown in figure

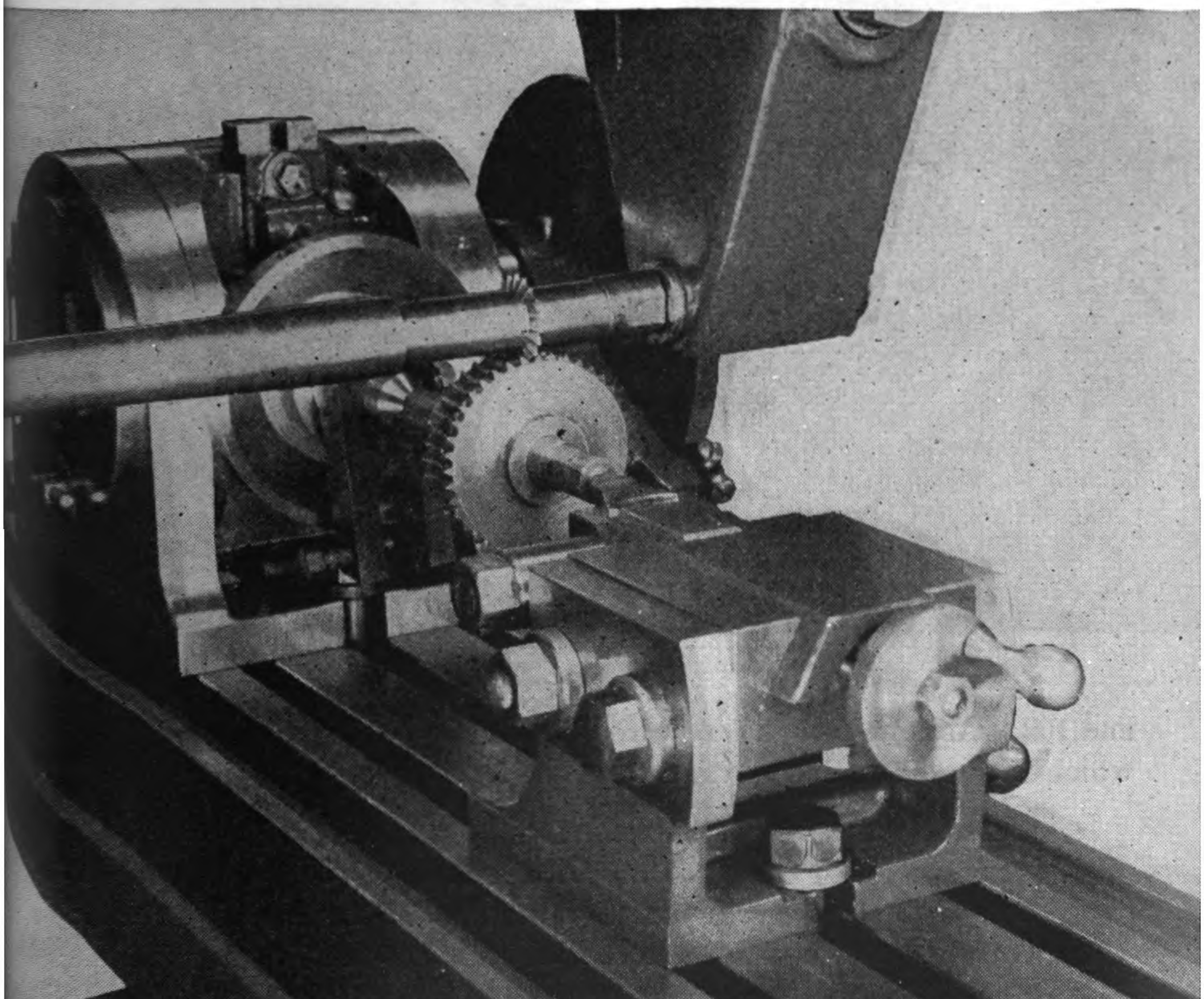


FIGURE 101.—Gashing the teeth in a worm wheel.

101 is not available, an involute spur gear cutter, for a corresponding number of teeth and pitch, may be used. If a worm wheel is finished by hobbing, as illustrated in figure 102, the hob selected should correspond to the worm wheel in diameter, pitch, and lead.

d. The following procedure is given as an example in the calculation and cutting of a worm wheel and is illustrated in figures 101

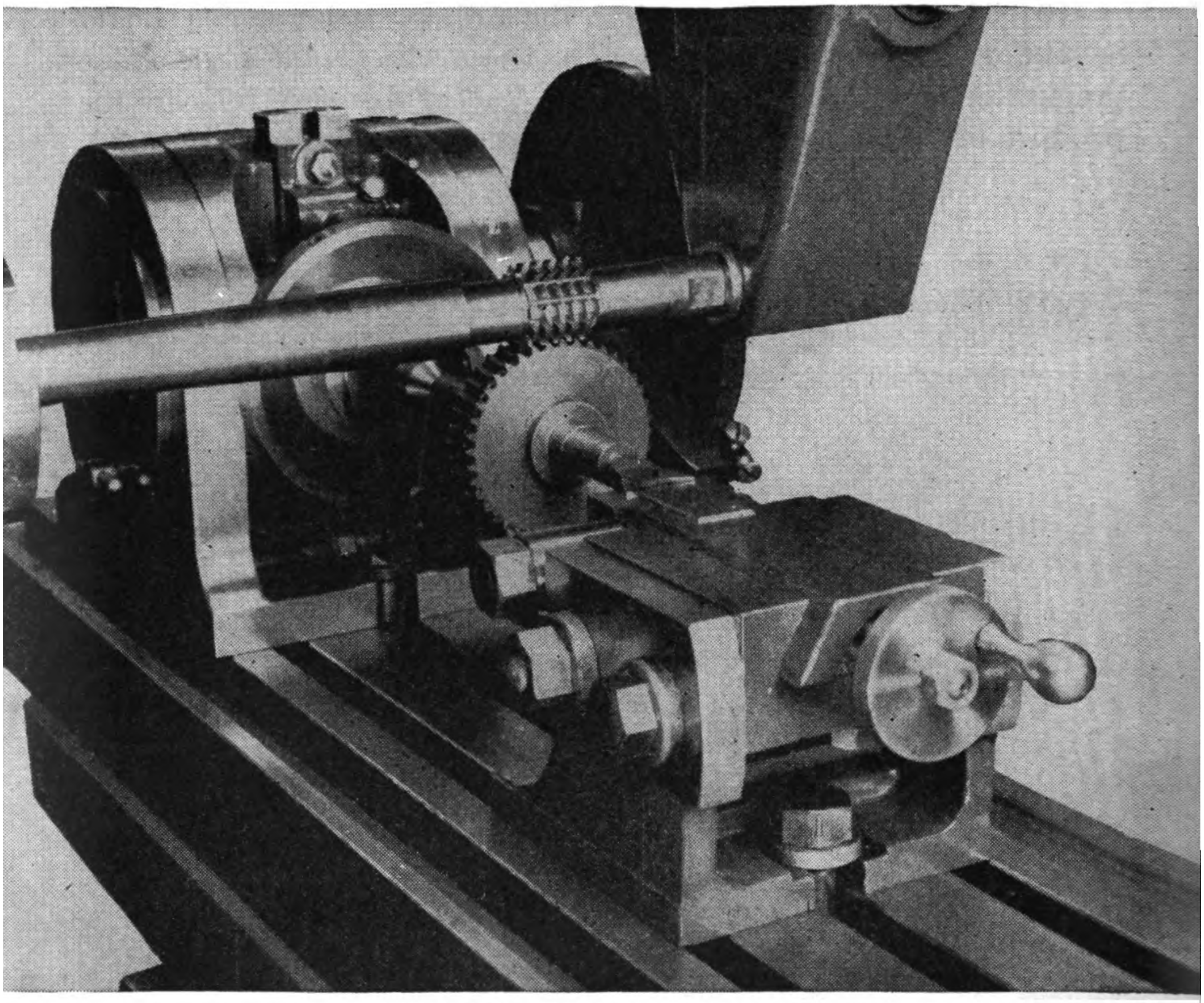


FIGURE 102.—Hobbing a worm wheel.

and 102. Assume that it is required to mill the teeth in a worm wheel which will mesh with a worm having the following dimensions:

Outside diameter of worm	1.5	inches
Pitch diameter of worm	1.341	inches
Linear pitch of worm (single thread)	0.250	inch
Addendum of worm thread	0.0795	inch
Ratio desired	40 to 1	
Center distance of shafts	2.262	inches

(1) Make the necessary calculations as follows:

Number of teeth on gear $(N)=40$

Pitch diameter of worm wheel $(D')=\frac{NP'}{3.1416}=\frac{40\times.250}{3.1416}=$ 3.183 inches

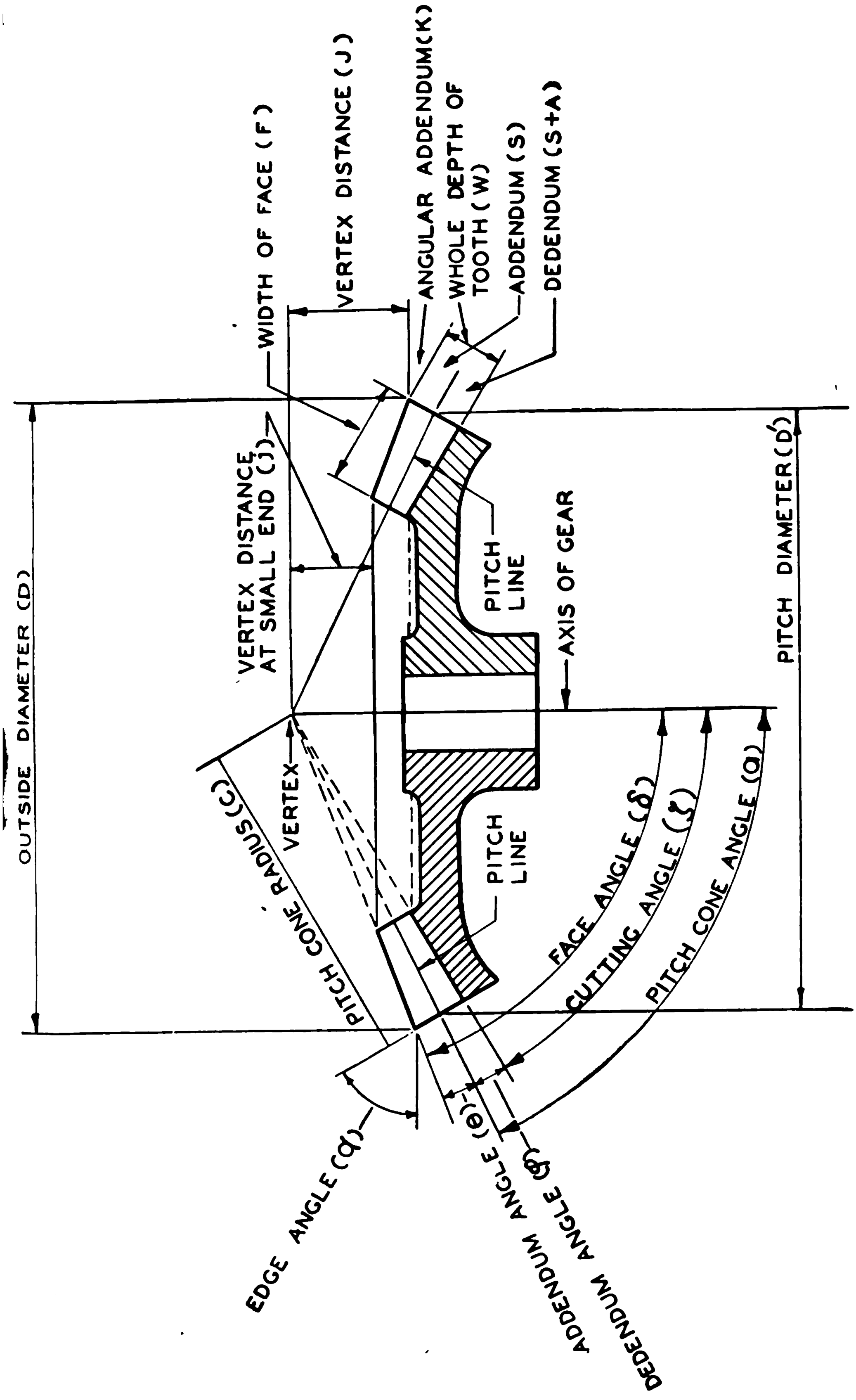


FIGURE 103.—Bevel gear nomenclature.

Diametral pitch $(P)=\frac{N}{D'}=\frac{40}{3.183}=12.566$ inches

Throat diameter $(D)=\frac{N}{P}+2s=\frac{40}{12.566}+0.1590=3.342$ inches

Circular pitch $(P')=\frac{3.1416\times D'}{N}=\frac{3.1416\times 3.183}{40}=0.250$ inch

Lead of worm $(L)=P'\times$number of threads in worm$=0.250\times 1=0.250$ inch

Gashing angle—

Tangent of angle=

$$\frac{L}{3.1416\times d'}=\frac{0.250}{3.1416\times 1.341}=0.05935 \text{ inch}$$

Angle$=3°24'$

Number of cutter—12 pitch No. 3. (Table XI.)

(2) Fasten the universal index centers to the milling machine table and aline if necessary.

(3) Press the gear blank on a lathe mandrel and mount on the index centers. The mandrel is driven by a dog secured to the headstock center.

(4) Set the universal milling machine table at right angles and secure a No. 3, 12-pitch involute gear cutter on the arbor. The cutter should be alined centrally as previously described.

(5) Set the table at the gashing angle of 3°24′.

(6) Arrange the index head to index 40 teeth.

(7) With the cutter revolving, raise the milling machine knee until the gear blank touches the cutter. The graduated dial on the vertical feed is then locked and by using this dial as a guide, the blank is raised the number of thousandths of an inch needed to cut the tooth space. This setting should allow for a small amount of material to be removed by means of a hob. After the cut is made the vertical feed stop should be locked and the knee lowered to clear the work and cutter. The worm wheel is then indexed, and the knee raised to the stop to cut another tooth space. This process is repeated until all the teeth are gashed.

(8) Remove the gashing cutter from the arbor and replace it with the proper type hob. After mounting, the hob must be located centrally with the gashed worm gear and the longtitude and transverse feeds locked.

(9) Set the milling machine swivel table at zero and lock it in this position.

(10) Remove the dog from the mandrel, allowing the worm wheel to be rotated freely on the centers by the hob.

(11) With the hob revolving, raise the knee slowly until the hob begins to cut. After the cut is started, the knee is raised slightly with each complete revolution of the worm wheel until the distance between the top of the knee and a marked center line on the vertical slide equals the center distance of the worm and worm wheel. The marked center line on the vertical slide indicates the position of the top of the knee when the index centers are at the same height as the center of the milling machine spindle. This center distance may be measured by using a steel rule at the back of the knee.

39. Bevel gears.—*a.* Bevel gears, shown in figure 92⑥, are used to transmit motion through shafts that are not parallel and may be designed to meet at any angle. They are often called miter gears when their shafts are at right angles and both have the same number of teeth. Most bevel gears have the involute form of tooth with either a 14½° or 20° pressure angle; the former being the more commonly used. Bevel gears are usually manufactured by a generating process, due to the peculiar shape of the tooth; however, when only small numbers are to be cut, the milling machine is commonly used in the general shop.

b. The following is an explanation of the symbols and formulas involved in the calculation and milling of bevel gears whose shafts meet at right angles. The various symbols are illustrated in figure 103.

(1) The pitch cone angle of the pinion (αp) is the angle whose tangent is determined by dividing the number of teeth in the pinion (Np) by the number of teeth in the gear (Ng).

$$\text{Tan } \alpha p=\frac{Np}{Ng}$$

(2) The pitch cone angle of the gear (αg) is the angle whose tangent is determined by dividing the number of teeth in the gear (Ng) by the number of teeth in the pinion (Np).

$$\text{Tan } \alpha g=\frac{Ng}{Np}$$

(3) As a check of above calculations for pitch cone angles, the results should be added and if their sum equals 90°, the calculations may be assumed to be correct. $\alpha p+\alpha g=90°$.

(4) The pitch diameter (D') may be determined by dividing the number of teeth (N) by the diametral pitch (P).

$$D'=\frac{N}{P}$$

(5) The addendum at the large end of the tooth (S) is equal to the quotient obtained by dividing the number 1 by the diametral pitch (P).

$$S=\frac{1.0}{P}$$

(6) The dedendum at the large end of the tooth ($S+A$) may be obtained by dividing 1.157 by the diametral pitch.

$$S+A=\frac{1.157}{P}$$

(7) The whole depth of tooth space (W) may be determined by dividing 2.157 by the diametral pitch (P).

$$W=\frac{2.157}{P}$$

(8) The thickness of the tooth at the pitch line (T) is equal to the quotient obtained by dividing 1.571 by the diametral pitch (P).

$$T=\frac{1.571}{P}$$

(9) The pitch cone radius (C) may be determined by dividing the pitch diameter (D') by twice the sine of the pitch cone angle (α).

$$C=\frac{D'}{2\times\text{sine }\alpha}$$

(10) The width of face (F) is made ⅓ the pitch cone radius for gears up to 3 inches in pitch diameter and ¼ of the pitch cone radius for gears having 3 to 20 inches of pitch diameter.

$$F=\frac{C}{3}\text{ or }\frac{C}{4}$$

(11) The addendum at the small end of the tooth (s) may be determined by subtracting the width of face (F) from the pitch cone radius (C); dividing the remainder by the pitch cone radius and multiplying this quotient by the major addendum (S).

$$s=S\times\frac{C-F}{C}$$

(12) The thickness at the pitch line for the small end of the tooth (t) is found by subtracting the width of face (F) from the pitch cone radius (C); dividing the remainder by the pitch cone radius and

multiplying the quotient by the thickness of the tooth at the large end (T), measured at the pitch line.

$$t=T\times\frac{C-F}{C}$$

(13) The addendum angle (θ) for either the gear or the pinion is the angle whose tangent is determined by dividing the major addendum (S) by the pitch cone radius (C).

$$\text{Tangent } \theta=\frac{S}{C}$$

(14) The face angle (δ) is equal to the sum of the pitch cone and addendum angles. $\delta=\alpha+\theta$

(15) The cutting angle (ζ) is determined by the Brown and Sharpe system in which the clearance at the bottom of the tooth is made uniform instead of tapering toward the vertex. In this system the cutting angle may be determined by subtracting the addendum angle (θ) from the pitch cone angle (α).

$$\zeta=\alpha-\theta$$

(16) The angular addendum (K) may be determined by multiplying the major addendum (S) by the cosine of the pitch cone angle (α).

$$K=S\times\text{cosine } \alpha$$

(17) The outside diameter (D) may be determined by adding twice the angular addendum ($2K$) to the pitch diameter (D').

$$D=D'+2K$$

(18) The vertex distance (J) may be determined by multiplying one-half the outside diameter (D) by the tangent of the face angle (δ).

$$J=\frac{D}{2}\times\text{tangent } \delta$$

(19) The vertex distance at the small end of the tooth (j) may be found by subtracting the width of face (F) from the pitch cone radius (C); dividing the remainder by the pitch cone radius and multiplying this quotient by the major vertex distance (J).

$$j=J\times\frac{C-F}{C}$$

(20) The number of teeth for which to select the cutter may be determined by dividing the number of teeth in the gear (N) by the cosine of the pitch cone angle (α).

$$N'=\frac{N}{\text{cosine } \alpha}$$

(21) The chordal thickness of tooth (T'') is used where accurate measurement of a gear tooth is desired. The chordal thickness of a bevel gear is the same as that of a spur gear having an equal pitch and number of teeth.

(22) The chordal thickness of the small end of the gear tooth (t'') may be determined by subtracting the width of the face (F) from the pitch cone radius (C); dividing the remainder by the pitch cone radius and multiplying this quotient by the chordal thickness of the tooth at the large end (T'').

$$t'' \text{ at the small end} = T'' \text{ at the large end} \times \frac{C-F}{C}$$

(23) For accurate measurement of a gear, in addition to having the chordal thickness of the tooth, the corrected pitch depth (H) must be determined. This dimension may be found for a bevel gear by using the following formula:

$$H = S + \frac{C}{\text{cosine } \alpha} \times (1 - \text{cosine } \beta)$$

Where:

S = the addendum
C = the pitch cone radius
α = the pitch cone angle
β = the angle subtended by lines from the apex of the back cone intersecting one side and the center of the tooth respectively at the pitch line.

In this formula β is the angle whose sine is found as follows:

$$\text{Sine } \beta = \text{sine}\left(\frac{90}{N}\right) \times \text{ cosine } \alpha$$

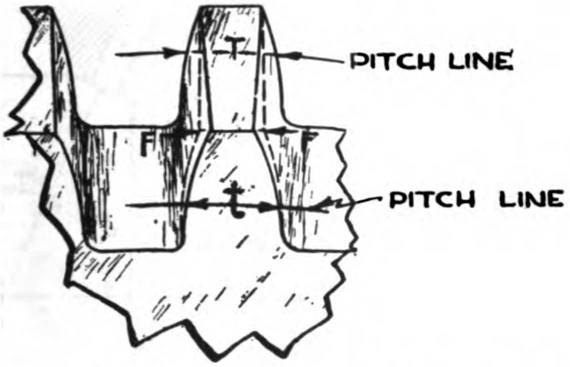
Where:

N = number of teeth

(24) The corrected pitch depth for the small end of the bevel gear tooth (h) may be determined by subtracting the width of the face (F) from the pitch cone radius (C); dividing the remainder by the pitch cone radius and multiplying this quotient by the corrected pitch depth of the tooth at the large end (H).

$$h = H \times \frac{C-F}{C}$$

c. In selecting the cutter, the shape of the gear tooth space must be taken into consideration, due to the fact that the tooth space at the inner end of the tooth is narrower than at the outer end. For this reason, the cutter must have a curve that will produce the correct form at the large end of the tooth and yet be of such a thickness that it will not cut the tooth space at the small end too wide. Cutters, manufactured particularly for cutting bevel gears, are similar in appearance and size to those used for cutting spur gears. However, due to the tooth space width of the small end, bevel gear cutters are made thinner than those used for cutting spur gears. Since the cutter is selected to give the correct form of tooth at the large end, the tooth curve will be too nearly straight at the small end. The general practice is to eliminate this condition by filing the small end of the tooth to the correct curve, as shown in figure 104. Rules used in the



T. Thickness of tooth at the pitch line on the large end of the tooth.
t. Thickness of tooth at the pitch line on the small end of the tooth.
F. Area to be removed by filing.

FIGURE 104.—Diagram of bevel gear tooth.

selection of cutters for bevel gear teeth may be given as follows:

(1) There are eight 14½° involute bevel gear cutters (numbering from 1 to 8) for each pitch required in cutting bevel gears from a 12-tooth pinion to a crown gear.

(2) The pitch of a bevel gear always refers to the large end of the teeth.

(3) Determination of the number of teeth for which the cutter should be selected is accomplished in the following manner:

(*a*) Draw a cross sectional view of the bevel gear and pinion to be cut, as shown in figure 105, making lines *AB* and *BC* at right angles and extending them to intersect the center lines of the gears.

(*b*) Measure the lengths *AB* and *BC*. The distance *AB* is the back cone radius of the gear and may be considered the radius of a hypothetical spur gear of the same pitch as the required bevel gear. Similarly, the distance *BC* is the back cone radius of the pinion and may be considered the radius of a hypothetical spur gear of the same pitch as the required pinion.

(*c*) Double each of the distances (*AB* and *BC*) to determine the diameters of the hypothetical spur gears referred to above, then multiply each product by the diametral pitch to find the number of teeth.

(*d*) Select the proper involute cutters for the gear and pinion according to the results obtained in step (*c*).

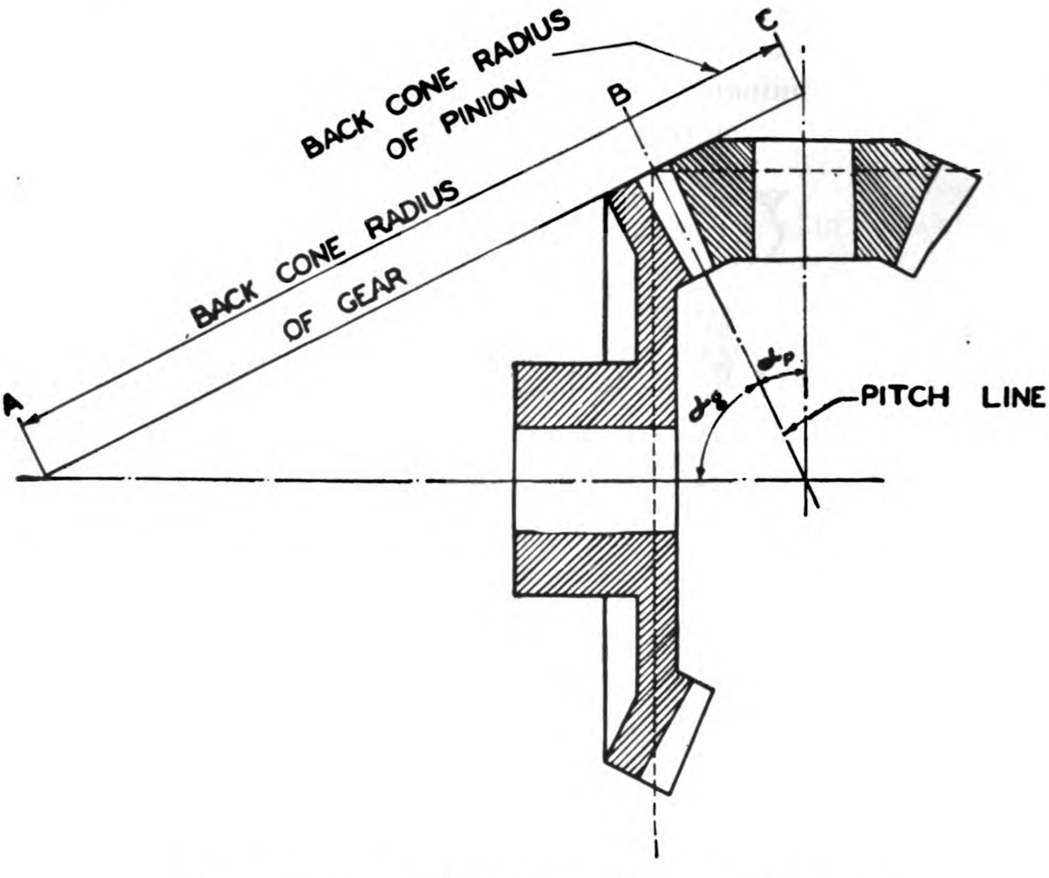


FIGURE 105.—Method of selecting a bevel gear tooth cutter.

(4) As an example in the above calculation, assume that it is required to select the proper cutter for the bevel gear and pinion illustrated in figure 105, and having the following specifications:

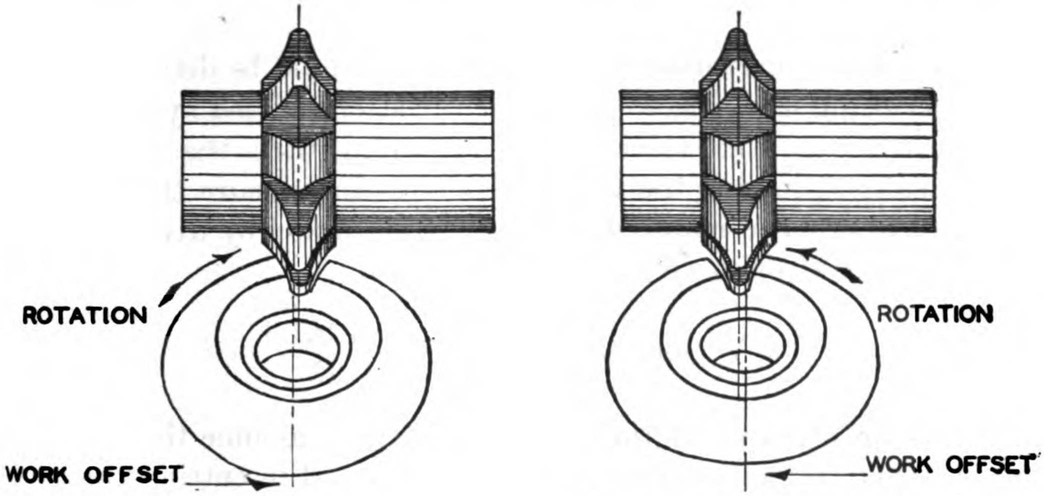
Number of teeth on gear	32
Number of teeth on pinion	16
Diametral pitch	8
Back cone radius of gear (by measurement).	
Back cone radius of pinion (by measurement).	

(*a*) Calculations for gear cutter—
Number of teeth in hypothetical spur gear$=5\times2\times8=80$
Cutter selection (table XI)$=$No. 2

(*b*) Calculation for pinion cutter—
Number of teeth in hypothetical spur gear=1.125×2×8=18
Cutter selection (table XI)= No. 6

d. As the thickness of the cutter is selected for the width of the tooth space at the small end of the tooth, it is necessary to set the cutter out of center with the blank, and rotate the blank, as illustrated in figure 106, to cut the spaces to the correct width at the large end of the tooth.

(1) The factors given in table XII are used to determine the amount of set-over for the work table. To use these offset values, the ratio of the pitch cone radius to the length of face must be found. To determine this ratio, the pitch cone radius should be divided by the



① Clockwise rotation. ② Counterclockwise rotation.

FIGURE 106.—Offset and rotation of work in bevel gear cutting.

width of the face. The ratio, given in the horizontal scale of the table, which most nearly approaches the ratio calculated, is the offset factor required. This factor may then be substituted in the following formula to give the correct amount to offset the work table.

$$\text{Table offset}=\frac{Tc}{2}-\frac{\text{set-over factor}}{P}$$

Where: P =diametral pitch of gear to be cut
Tc=thickness of cutter, measured at the pitch line

TABLE XII.—*Set-over factors for bevel gear cutters*

Number of cutter	Ratio of pitch cone radius to length of face												
	$\frac{3}{1}$	$\frac{3\frac{1}{4}}{1}$	$\frac{3\frac{1}{2}}{1}$	$\frac{3\frac{3}{4}}{1}$	$\frac{4}{1}$	$\frac{4\frac{1}{4}}{1}$	$\frac{4\frac{1}{2}}{1}$	$\frac{4\frac{3}{4}}{1}$	$\frac{5}{1}$	$\frac{5\frac{1}{2}}{1}$	$\frac{6}{1}$	$\frac{7}{1}$	$\frac{8}{1}$
	Set-over factor (inches)												
1	0.254	0.254	0.255	0.256	0.257	0.257	0.257	0.258	0.258	0.259	0.260	0.262	0.264
2	.266	.268	.271	.272	.273	.274	.274	.275	.277	.279	.280	.283	.284
3	.266	.268	.271	.273	.275	.278	.280	.282	.283	.286	.287	.290	.292
4	.275	.280	.285	.287	.291	.293	.296	.298	.298	.302	.305	.308	.311
5	.280	.285	.290	.293	.295	.296	.298	.300	.302	.307	.309	.313	.315
6	.311	.318	.323	.328	.330	.334	.337	.340	.343	.348	.352	.356	.362
7	.289	.298	.308	.316	.324	.329	.334	.338	.343	.350	.360	.370	.376
8	.275	.286	.296	.309	.319	.331	.338	.344	.352	.361	.368	.380	.386

The thickness, measured at the pitch line, should be determined for the cutter being used, due to the slight variations caused by regrinding of the cutters. This thickness is measured with the gear tooth vernier caliper, having the vertical slide set to measure the cutter at the pitch line. The required setting is determined by dividing 1.157 by the diametral pitch (P).

$$\text{Vernier caliper setting} = \frac{1.157}{P}$$

(2) As an example of the above calculation, assume that it is required to determine the amount of offset required in cutting the bevel gear illustrated in figure 105, which has a pitch cone radius of 2.309 inches, and a face width of 0.770 inches.

(*a*) By referring to the cutter calculations previously given, it will be found that the cutter selected was a No. 2.

(*b*) The ratio of the pitch cone radius to the length of face is:

$$\frac{2.309}{0.770} = \frac{3}{1}$$

(*c*) According to table XII, the factor most nearly corresponding to the above ratio is found to be 0.266 inches.

(*d*) The thickness at the pitch circle of the No. 2, 8-pitch cutter is 0.1644 inch.

(*e*) Substituting these values in the formula, the amount of offset is found to be 0.048 inch.

$$\frac{0.1644 \text{ inch}}{2} - \frac{0.266 \text{ inch}}{8} = 0.048 \text{ inch}$$

(3) As previously discussed, it is necessary to rotate the gear blank when trimming the sides of the teeth. The amount of rotation may best be determined by the cut and check method, as outlined below.

(*a*) Two adjacent tooth spaces are cut in the gear blank with the cutter set centrally.

(*b*) The cutter is then set off center the required amount, as calculated above, by moving the milling machine table transversely, and gaging the amount of movement by the graduated dial on the transverse feed.

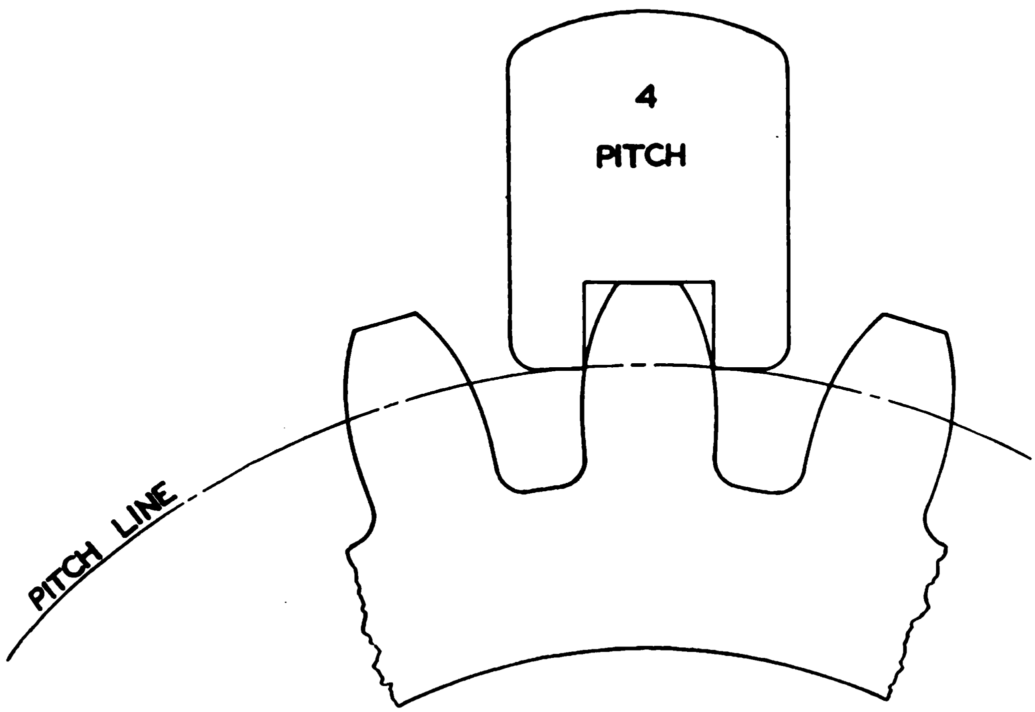


FIGURE 107.—Measuring bevel gear teeth.

(*c*) By indexing, the gear should be rotated in an opposite direction from that in which the table is moved off center, allowing the side of the cutter nearest the center line of the gear to cut the entire surface of the approaching side of the tooth.

(*d*) The work is then moved away from the cutter, the table offset the proper distance on the opposite side of center, and the operations of rotating and cutting the tooth repeated. The gear tooth so trimmed should be measured at the large end by using the gear tooth vernier caliper, shown in figure 95, or a gage such as shown in figure 107. Corrections may then be made on the basis of the vernier reading. In making these corrections, it is well to remember that a cutter set too much out of center leaves the small end of the tooth too thick, and one that is not offset enough leaves the small end too thin.

In cutting the teeth, it is better to have a slight variation in depth than an incorrect thickness of teeth.

e. The following procedure is given as an example in the calculation and milling of a bevel gear. Assume that it is required to cut a 24 tooth gear having a diametral pitch of 5, a pitch cone angle of 45° and a shaft angle of 90°.

(1) Make the necessary calculations as follows:

Pitch diameter $(D') = \frac{N}{P} = \frac{24}{5} = 4.8$ inches

Pitch cone angle $(\alpha) = 45°$

Addendum $(S) = \frac{1.0}{P} = \frac{1.0}{5} = 0.20$ inch

Angular addendum $(K) = S \times \text{cosine } \alpha = 0.20 \times 0.707 = 0.1414$ inch

Outside diameter $(D) = D' + 2K = 4.8 + .283 = 5.083$ inches

Pitch cone radius $(C) = \frac{4.8}{2 \times \text{sine } \alpha} = \frac{4.8}{2 \times .707} = 3.3945$ inches

Addendum angle (θ)—

Tangent $\theta = \frac{S}{C} = \frac{0.2}{3.394} = 0.0589$ inch

Angle $\theta = 3°22'$

Face angle $(\delta) = \alpha + \theta = 45° + 3°22' = 48°22'$

Cutting angle $(\zeta) = \alpha - \theta = 45° - 3°22' = 41°38'$

Circular pitch at large end $(P') = \frac{3.1416}{P} = \frac{3.1416}{5} = 0.6283$ inch

Width of face $(F) = \frac{C}{4} = \frac{3.394}{4} = 0.848$ inch

Tooth thickness at pitch line on large end (T)

$$= \frac{1.571}{P} = \frac{1.571}{5} = 0.314 \text{ inch}$$

Tooth thickness at pitch circle on small end $(t) = T \times \frac{C-F}{C}$

$$= 0.314 \times \frac{3.394 - .848}{3.394} = 0.235 \text{ inch}$$

Addendum at small end $(s) = S \times \frac{C-F}{C}$

$$= 0.20 \times \frac{3.394 - 0.848}{3.394} = 0.150 \text{ inch.}$$

Whole depth at large end $(W) = \frac{2.157}{P} = \frac{2.157}{5} = 0.431$ inch

Dedendum at large end $(S+A) = \frac{1.157}{P} = \frac{1.157}{5} = 0.231$ inch

(2) Mount the blank on a tapered shank mandrel and insert the mandrel into the universal index head spindle as illustrated in figure 108.

(3) Set the index head to the proper cutting angle, as shown in figure 109, and arrange the indexing for the number of teeth to be cut.

(4) Using a bevel gear depth gage of the proper pitch, as shown in figure 110, or a depth of gear tooth micrometer, inscribe a line on the blank at the depth to which the large end of the tooth will be milled.

(5) Set the cutter centrally and lock the transverse feed graduated dial.

(6) Mill one tooth space then, by using the index arrangement, revolve the gear blank and cut an adjacent tooth space.

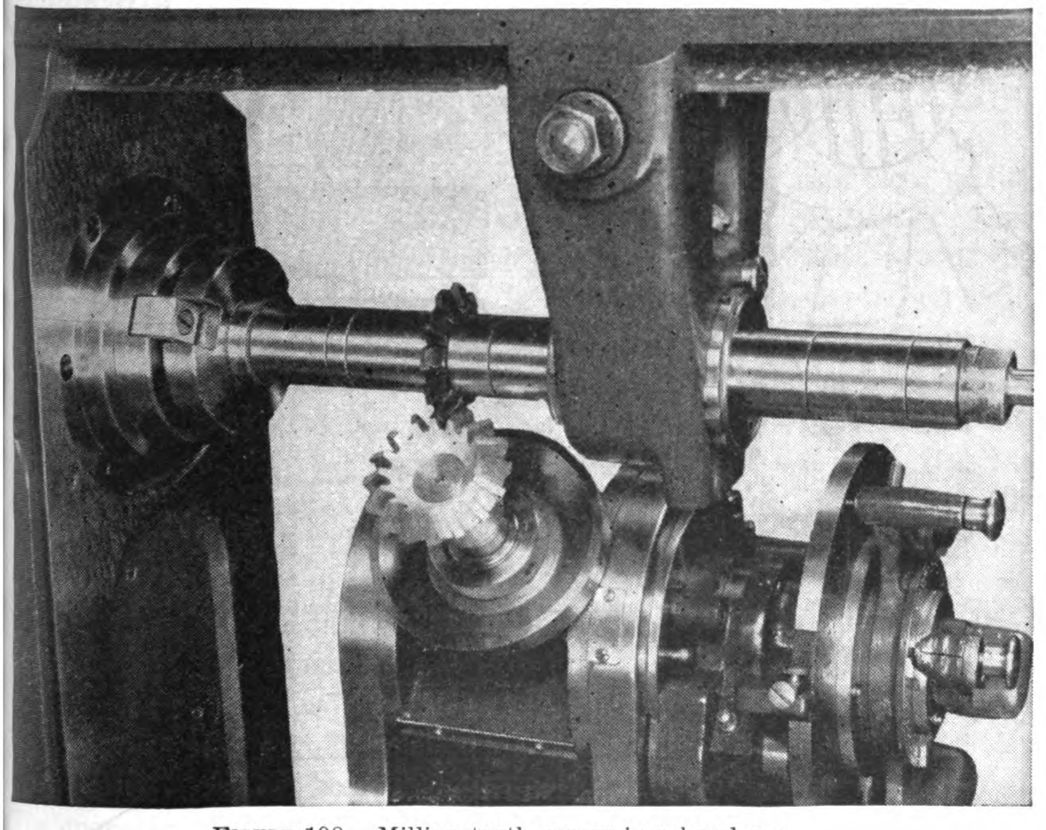


FIGURE 108.—Milling tooth spaces in a bevel gear.

(7) Using the transverse graduated dial as a guide, set the gear blank off center. The gear is then rotated by means of the index crank and the tooth is checked as previously discussed.

(8) After the proper adjustments have been made to produce a tooth of the desired size, index and mill the remaining tooth spaces.

(9) Move the work away from the cutter and adjust the machine and cutter for trimming of the remaining side of the teeth.

(10) Remove the blank from the arbor and file the faces of the teeth slightly above the pitch line as indicated at points (*F*) in figure 104.

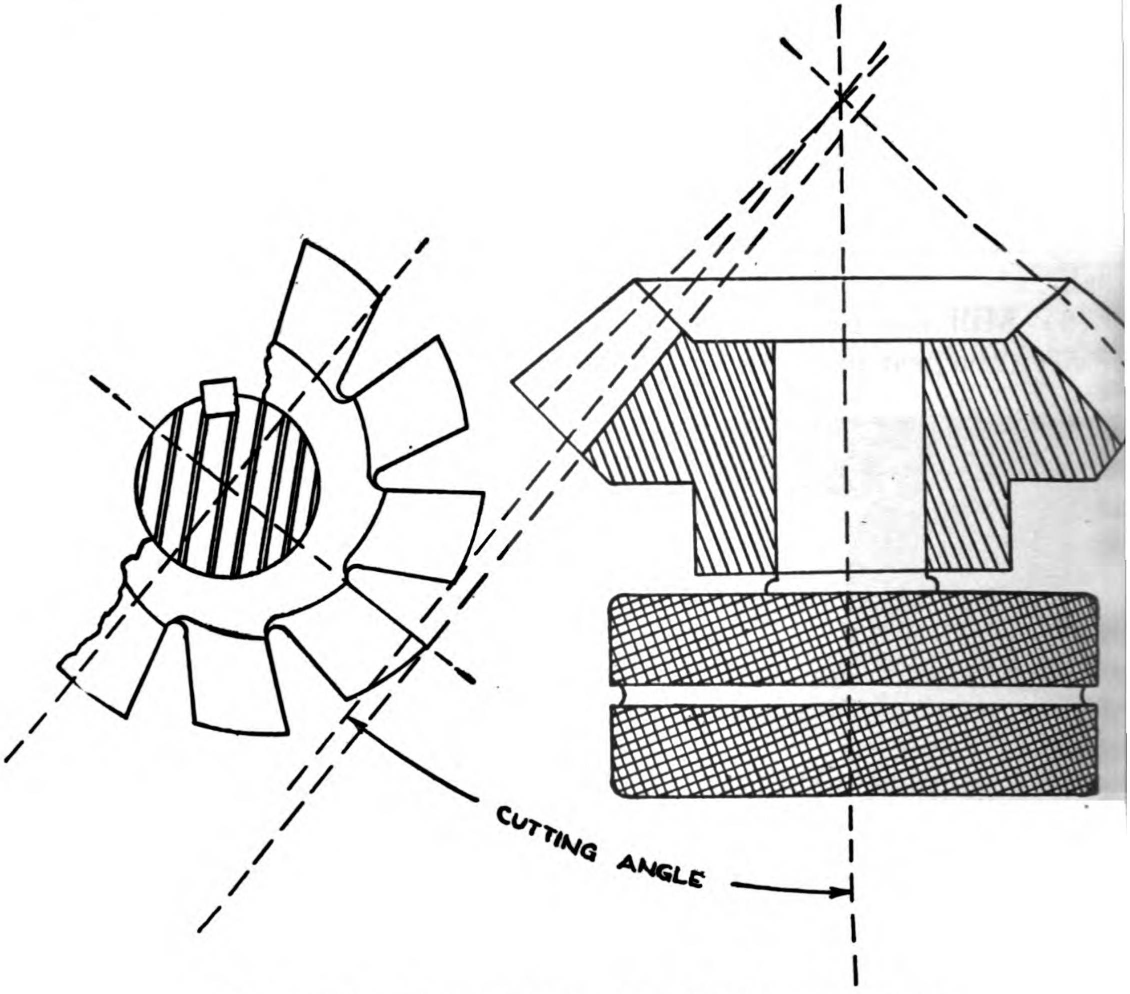


FIGURE 109.—Alinement and setting of bevel gear and cutter.

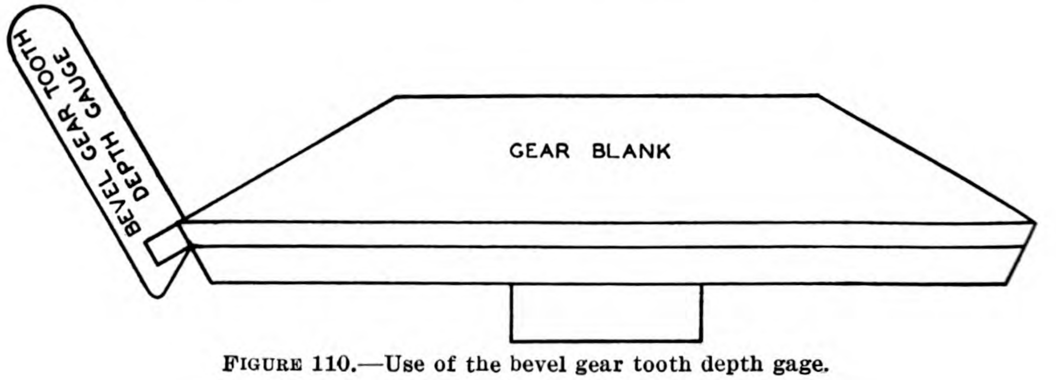


FIGURE 110.—Use of the bevel gear tooth depth gage.

SECTION VI

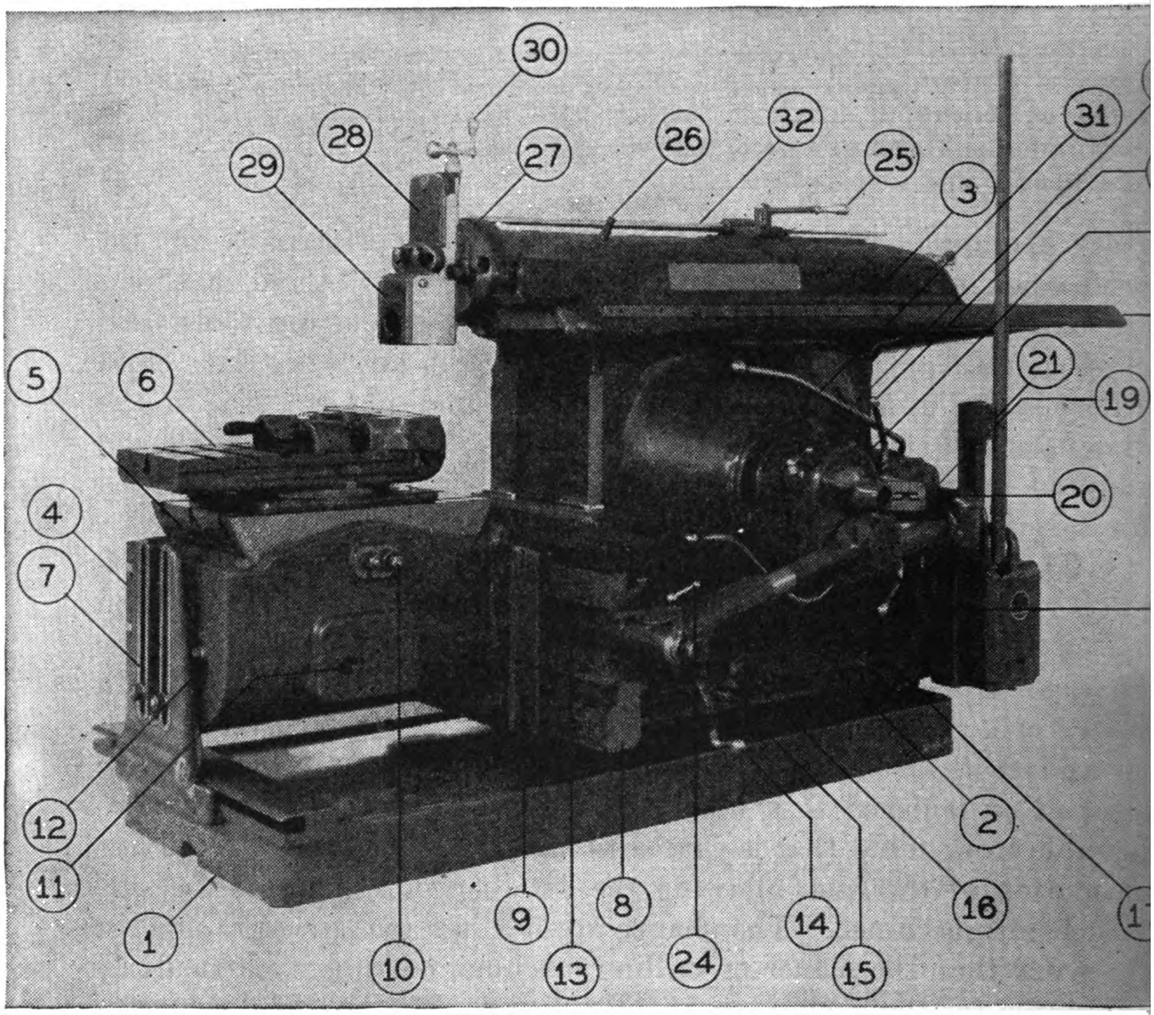
DESCRIPTION AND MAINTENANCE OF SHAPERS AND PLANERS

40. General.—Shapers and planers are used principally for the production of flat and angular surfaces. Both of these machines are designed to make straight line cuts and the cutting tools used in each case are identical with the exception of size. The chief difference in application between shapers and planers lies in the dimensions of the work that can be accommodated; the shaper being adapted to small and medium size pieces while the planer is suited for large production operations.

a. The shaper (fig. 111) may be defined as a machine tool, utilizing a reciprocating ram for carrying the cutter. With the exception of the drawcut shaper, the cutting action of the tool is on the forward stroke of the ram, which is delivered at a slower speed than the return stroke. The tool marks produced in this way are parallel and even across the work, giving a surface that may easily be scraped or polished to a high finish. The work is held on an adjustable work table, that is caused to move at right angles to the line of motion of the ram, allowing the cut to progress across the surface being machined. The shaper applies less tool pressure against the work than the planer or milling machine, making it particularly adaptable for the machining of light pieces. The size of a shaper is designated by the maximum length of its stroke; thus, a 24-inch shaper will machine work up to 24 inches in length.

b. The planer (fig. 112) is rigidly constructed and is especially suited for machining large, heavy work, where long cuts are required. The operation of the planer may be considered as being the reverse of that of the shaper, inasmuch as the reciprocating motion is produced by the work table, while the cutting tool is caused to feed at right angles to this motion to allow the cut to advance. As in the case of the shaper, the planer cuts only on the forward stroke, after which the table is caused to make a quick return to bring the work into position for the next cut. The size of a planer is designated by the size of the largest work that can be clamped and machined on its table; thus, a 30-inch × 30-inch × 6-foot planer is one that can accommodate work up to these dimensions.

41. Types of shapers.—Shapers may be divided into seven dis-

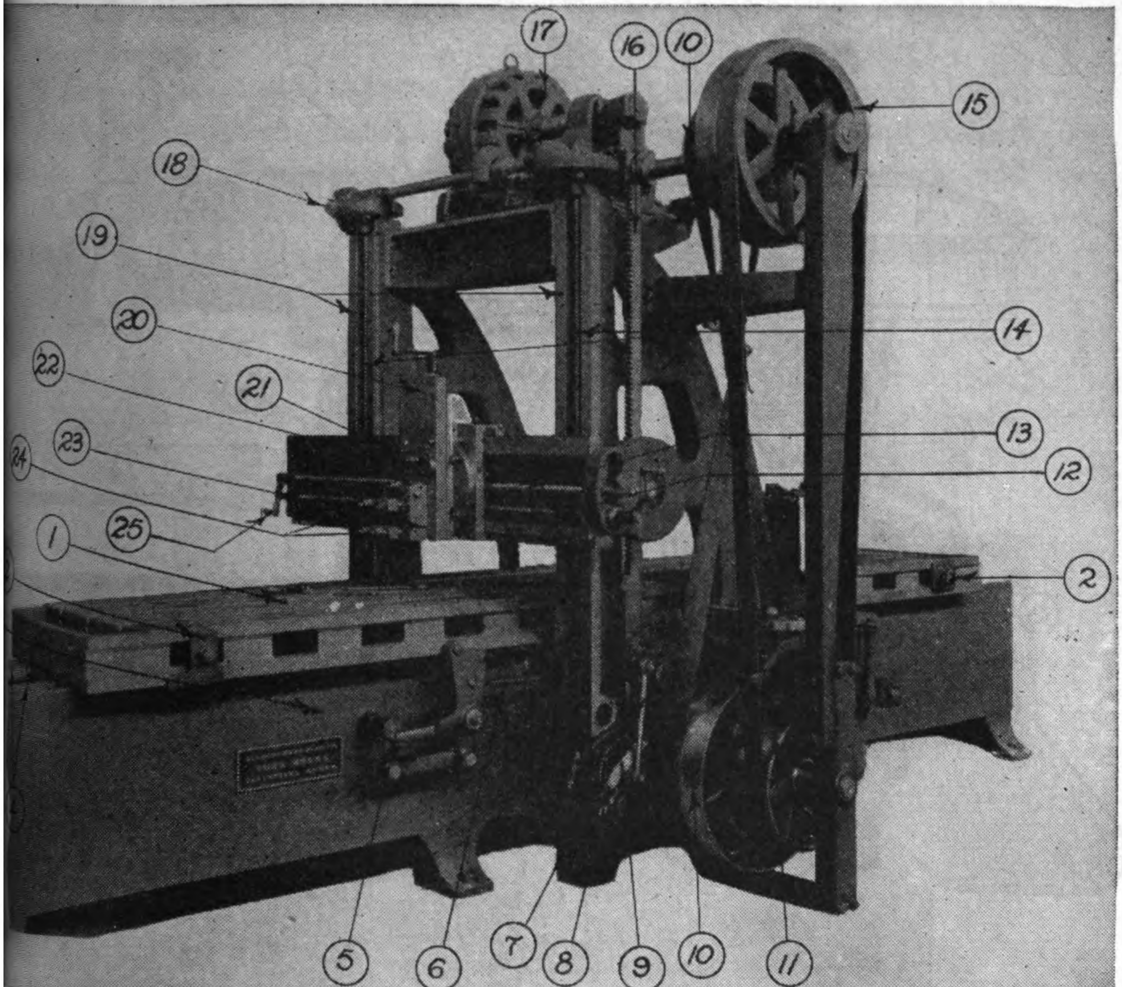


1. Base.	12. Table graduations.	23. Feed dial.
2. Column.	13. Table feed screw.	24. Feed engagement lever.
3. Ram.	14. Cross feed lever.	25. Ram clamp handle.
4. Table.	15. Cross rail elevating shaft.	26. Ram positioning shaft.
5. Tilting table.	16. Rocker arm shaft.	27. Swivel.
6. Vise.	17. Rapid traverse lever.	28. Tool slide.
7. Table bracket.	18. Gear shifter lever.	29. Clapper.
8. Cross rail.	19. Speed plate.	30. Ball crank.
9. Trunnion apron.	20. Speed change box.	31. Clutch lever.
10. Tilting table clamp.	21. Motor switch.	32. Oil delivery pipe.
11. Worm shaft.	22. Stroke dial.	33. Guard.

FIGURE 111.—Universal crank shaper.

tinct classes, each of which is described in the following subparagraphs. The crank shaper is most generally used, although the various other types are particularly adapted for certain operations.

a. Crank shaper.—Shapers in this class are those in which the tool carrier or ram is caused to move by a crank arm connected to a driving gear or "bull wheel" by means of a crank pin. This driving mechanism is illustrated in the cutaway portion of figure 113.

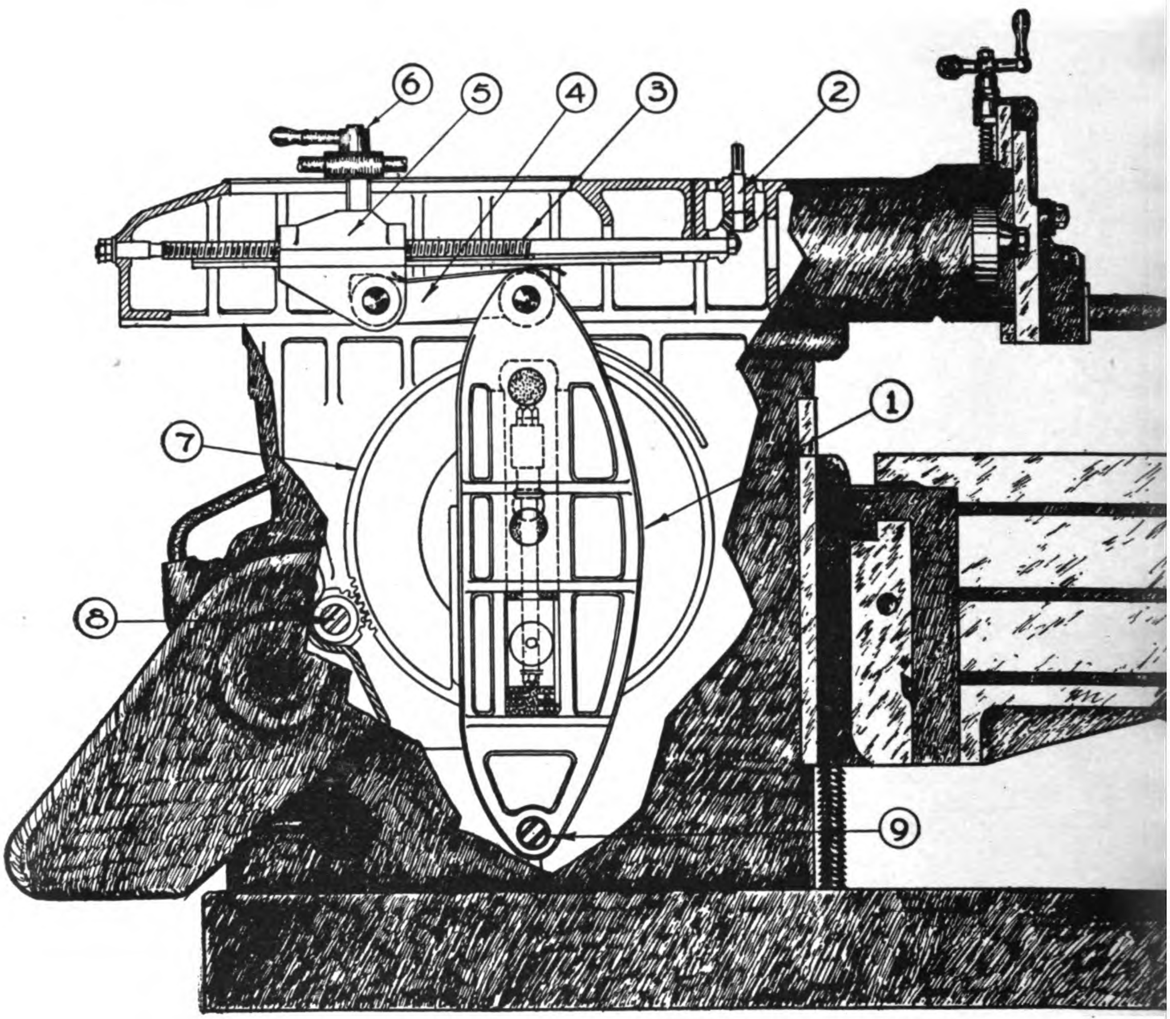


1. Table.
2. Table trip dogs.
3. Bed.
4. Vee-ways.
5. Belt shifter lever.
6. Feed cam link.
7. Feed rack connecting link.
8. Feed adjusting shaft.
9. Ratchet feed.
10. Driving pulleys.
11. Return pulley.
12. Cross feed screw.
13. Down feed shaft.
14. Elevating screws.
15. Return pulley.
16. Feed rack.
17. Motor.
18. Cross rail elevating shaft.
19. Housings.
20. Tool slide.
21. Cross rail.
22. Clapper box clamping nuts.
23. Clapper box.
24. Tool holding clamping nuts.
25. Down feed crank.

FIGURE 112.—Double housing planer.

(1) The crank shaper is manufactured in two types, the plain and the universal. Universal shapers have a work table that may be both swiveled and tilted, while the plain shaper table can only be moved vertically and horizontally.

(2) Where close adjustment of speed and feed is necessary a hydraulic control is often used. This feature gives a uniform cutting speed and allows a change in the length of stroke without altering the speed.



1. Rocker arm.
2. Ram positioning shaft.
3. Ram adjustment screw.
4. Link.
5. Ram adjustment nut.
6. Ram clamp handle.
7. Crank gear.
8. Crank gear pinion.
9. Rocker arm shaft.

FIGURE 113.—Shaper drive mechanism.

b. Geared shaper.—In geared shapers the ram is driven by a series of gears that provide both a speed range and a reversing action. The drive is accomplished by means of a rack fastened to the under side of the ram. As in the case of crank shapers, this machine is available in both the plain and universal types.

c. *Traveling head or transverse shaper.*—This type of shaper is designed for long work which is beyond the range of the crank or gear shapers. The unit consists of a long bed upon which two tables are mounted. The ram is attached to a saddle which feeds along the bed, at right angles to the motion of the ram, allowing the cut to progress across the work. The work tables are adjustable in the vertical plane only.

d. *Draw cut shaper.*—In this type of shaper, the tool is drawn or pulled through the metal being machined instead of being pushed along the cut. This feature allows heavier cuts to be made and tends to reduce vibration during the cut. The conventional ram is used and the general design of the machine is similar to that of the crank type.

e. *Vertical shaper.*—A vertical shaper (fig. 114) is one in which the ram moves with a vertical reciprocating motion, the driving mechanism being of either the crank or gear type. The work table may be revolved, making the machine particularly adaptable for cutting such work as internal gears, etc.

f. *Gear shaper.*—Gear shapers are used extensively in the aircraft and automotive industries for the rapid production of gear teeth. Gears are cut in this machine by causing a hardened cutter, shaped like a pinion gear, to pass across the face of the gear blank by means of a reciprocating ram.

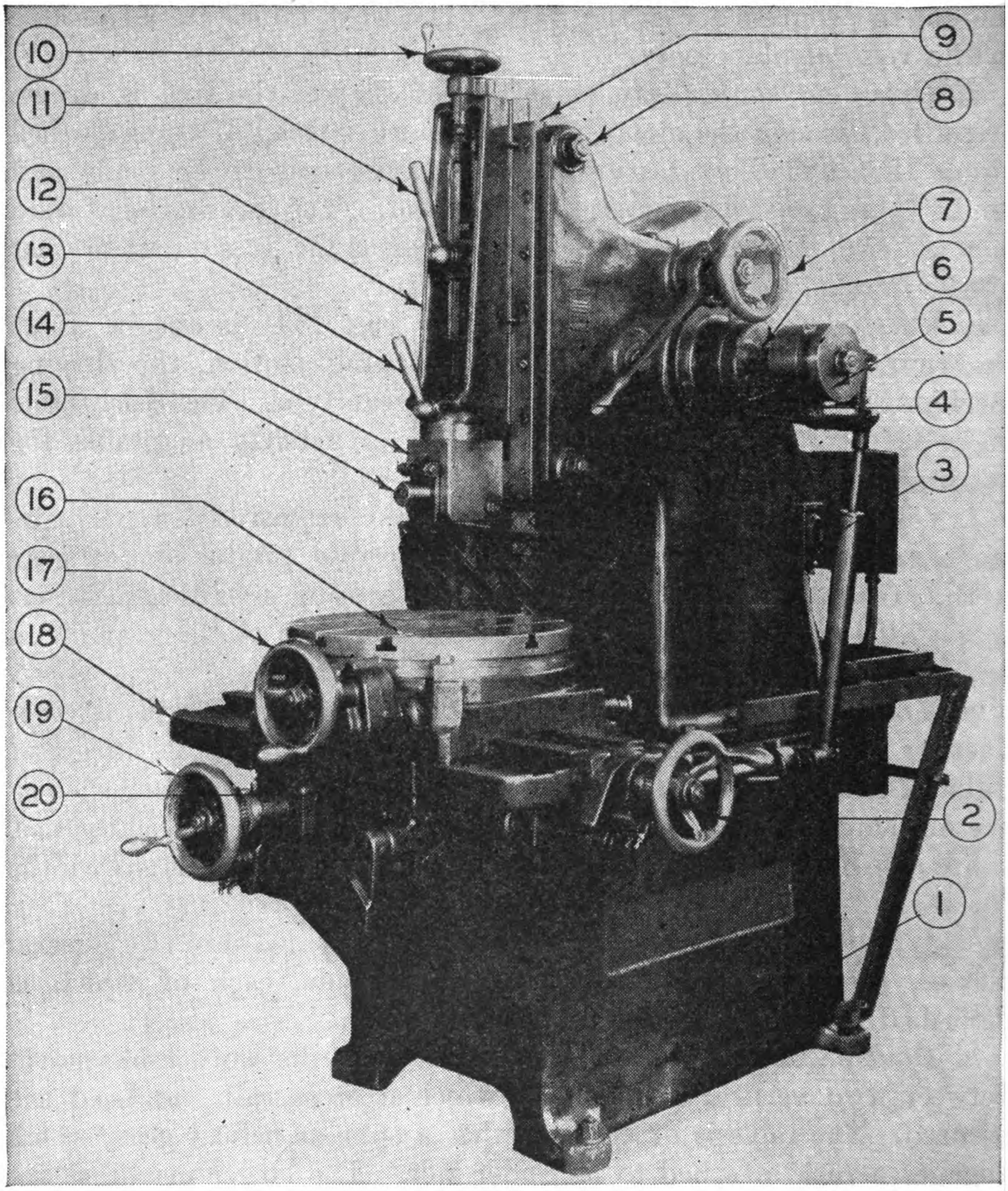
g. *Keyseating shaper or slotter.*—This machine is used in production work for cutting internal keyways such as those in gears, pulleys, and flywheels. The machine consists of a base which houses the mechanism for imparting a reciprocating motion to a cutter bar. Cutter bars are interchangeable and are furnished in different widths corresponding to the width of the keyway required.

42. Types of planers.—Planers may be divided into two general classes, the double housing and the open side, each of which is described below:

a. *Double housing planer.*—In this machine the work table moves between two vertical housings to which a cross rail and head are secured. The table is driven by either a spur or helical gear, which engages a rack attached to its under side. The larger machines are usually equipped with two cutting heads mounted to the cross rail as well as a side head mounted on each housing. With this set-up, it is possible to simultaneously machine both the side and the top surfaces of work mounted on the table.

b. *Open side planer.*—Planers of the open side type have but a single vertical housing, to which the cross rail is attached. The advantage of this design lies in the fact that work may be planed that is too wide to pass between the uprights of a double housing machine.

c. Either the double housing or open side planer may be equipped

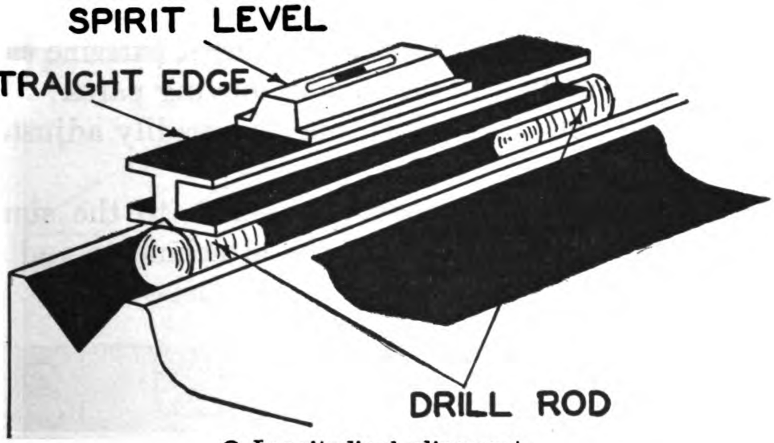


1. Bed.
2. Longitudinal hand wheel feed.
3. Motor switch.
4. Clutch lever.
5. Feed cam.
6. Stroke adjusting shaft.
7. Ram hand wheel.
8. Ram guide pivot shaft.
9. Ram guide.
10. Ram positioning wheel.
11. Link block binder lever.
12. Ram.
13. Tool block binder lever.
14. Tool block.
15. Tool post.
16. Rotary table.
17. Rotary table hand wheel.
18. Carriage slide.
19. Cross-feed hand wheel.
20. Carriage.

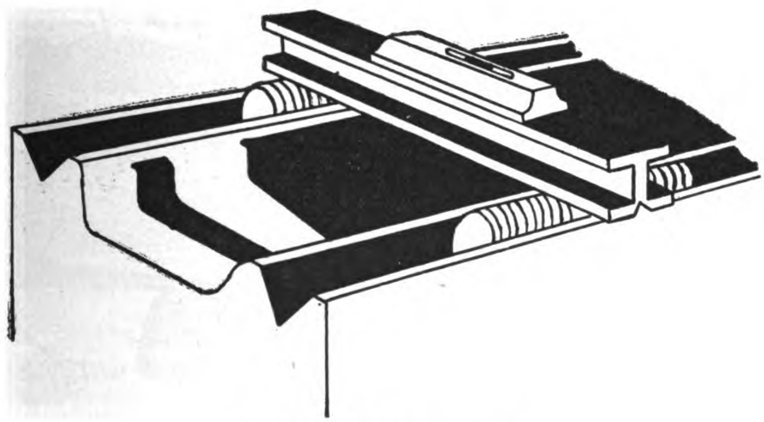
FIGURE 114.—Vertical shaper.

with an electrical, variable speed mechanism to give a wider range of speeds and a more sensitive control of the table.

43. Installation and maintenance of shapers and planers.—*a.* As in the case of milling machines, planers and shapers should be well supported by a heavy concrete floor and carefully leveled at the time of installation. Attachment should be made with heavy lag screws and leveling shims used where necessary.



① Longitudinal alinement.



② Transverse alinement.

FIGURE 115.—Leveling the planer.

b. After installation, regular leveling checks must be made to insure precision work and may be accomplished by means of an accurate level.

(1) In the case of the shaper, the check should be made on the ways of the ram as well as the work table.

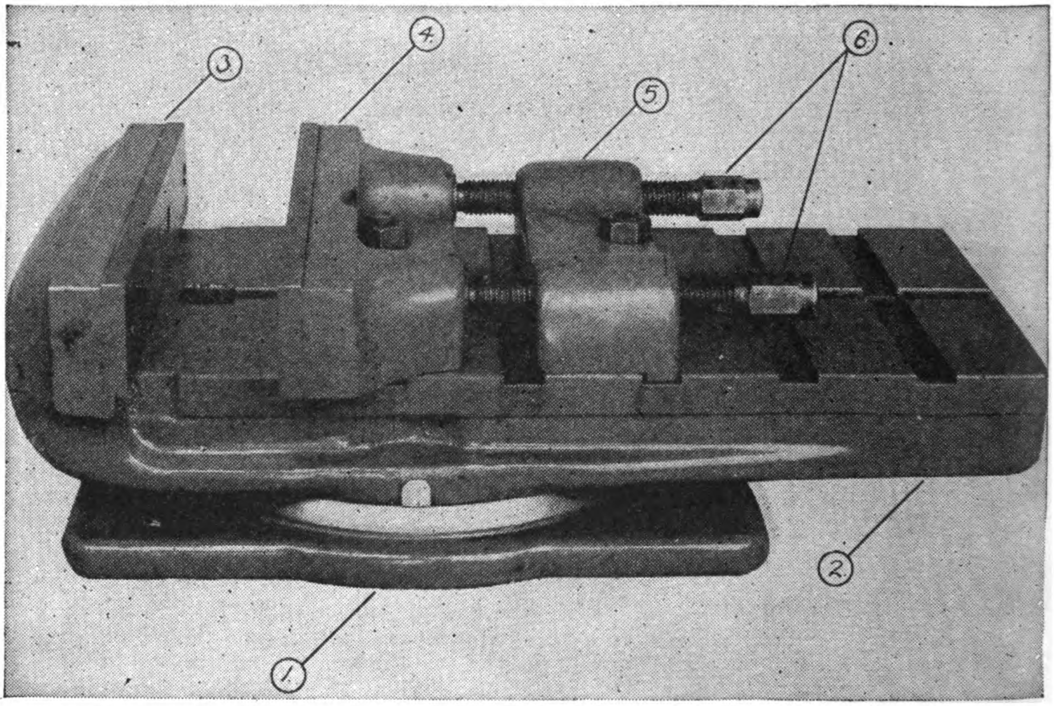
(2) When checking the level of a planer, the table, ways and cross rail, should be used as points of reference, as illustrated in figure 115.

c. The maintenance of these machine tools consists chiefly of the cleaning and lubricating of the parts and the making of adjustments to compensate for wear.

(1) *Cleaning and lubricating.*—Chips are best removed from the machine by means of a stiff bristle brush or compressed air. T-slots in the work table should be cleaned by means of a T-shaped scraper, while excess oil may be removed with a rag moistened with a solvent. All moving parts, bearing surfaces, and ways, should be kept lubricated with a good medium grade of engine oil.

(2) *Adjusting.*—In both shapers and planers, extreme care must be used to prevent lost motion in the various moving parts. Most sliding members are fitted with gibs which may be readily adjusted to compensate for wear.

44. Attachments and accessories.—Due to the similarity between planer and shaper operations, the attachments and accessories are identical for both machines.



1. Graduated base.
2. Vise body.
3. Fixed jaw.
4. Sliding jaw.
5. Vise back piece.
6. Vise screws.

FIGURE 116.—Swivel chuck or vise.

a. Attachments.—The vise (fig. 116) is the only standard attachment supplied with the shaper or planer. Attachments for special operations such as gear cutting, etc., may be obtained from the manufacturer.

b. Accessories.—The various accessories generally used in shaper and planer work may be described as follows:

(1) *Clamps.*—Various types of clamps are used to hold work on the work table and are attached by means of bolts to the table T-slots. The six standard types of clamps are illustrated in figure 117 while figure 54 shows correct and incorrect methods of clamp application. Accurately machined step blocks such as shown in figure 53⑥ are often used in connection with clamps to facilitate the holding of various shaped pieces.

(2) *Jacks.*—Jacks (fig. 118) are made in different sizes and are used to level and support work. The pointed screw (fig. 118②) replaces the swivel type screw for use in a corner. Extension bases (fig. 118③,

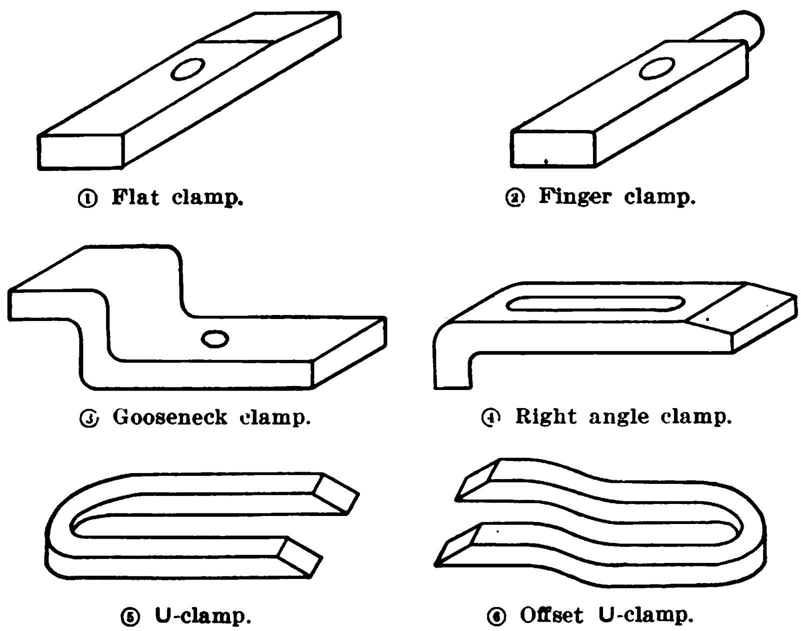


FIGURE 117.—Types of clamps.

④, ⑤, and ⑥) are used for increasing the effective height of the jack.

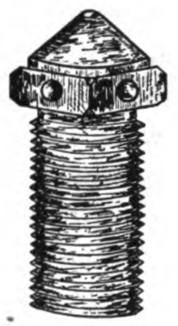
(3) *Parallels.*—(*a*) Rectangular parallels, such as described in the section on milling machines, are used to raise the work to the required height when held in the vise or clamped to the table.

(*b*) Degree parallels are similar to the rectangular type with the exception that one side is planed to a definite angle. These parallels are used for holding work when machining narrow surfaces to a required angle as illustrated in figure 119.

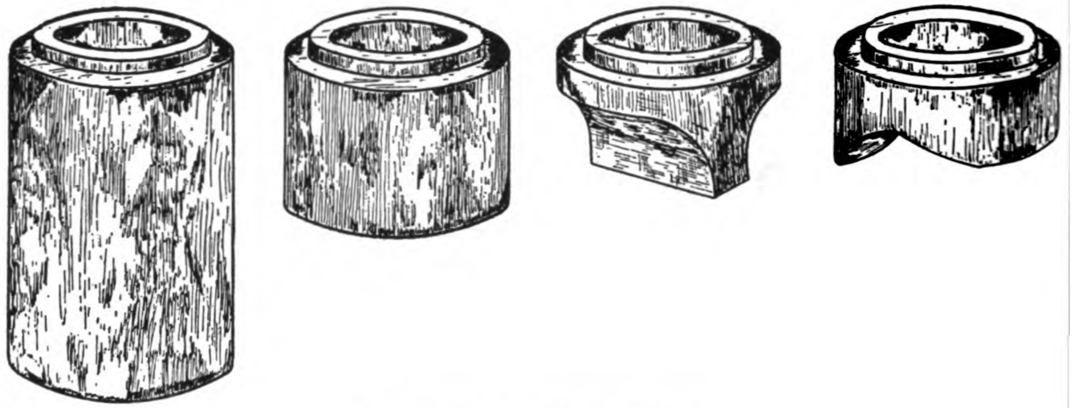
(4) *Hold-down straps.*—Hold-down straps or "grippers", of the type illustrated in figure 58, are very valuable in the holding of thin work in the vise.

(5) *Angle plates.*—Both adjustable and nonadjustable angle plates, of the type described for milling machines, are used extensively in shaper and planer work.

① Jack.



② Conical point screw.



③ ④ ⑤ and ⑥ Extension bases.

FIGURE 118.—Planer jack.

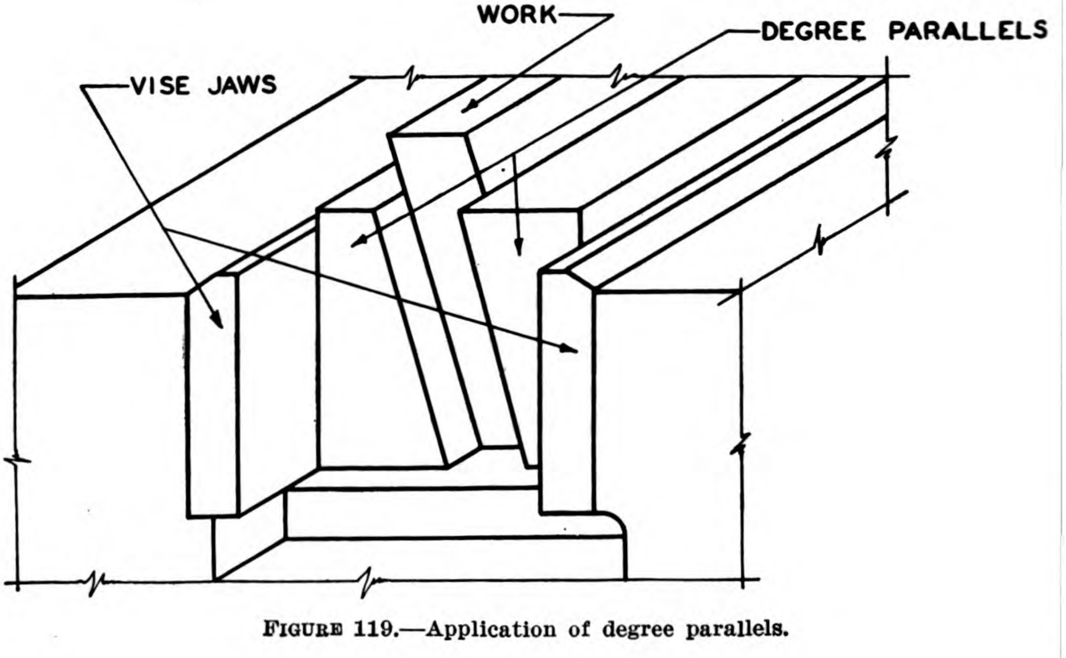
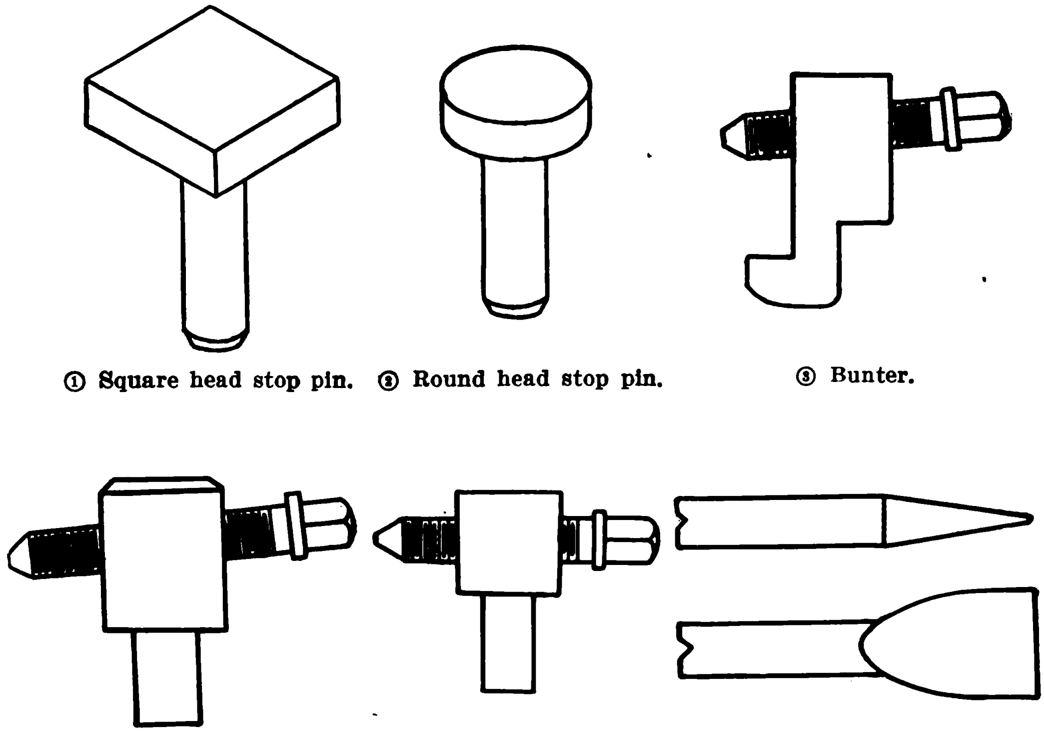


FIGURE 119.—Application of degree parallels.

(6) *Miscellaneous work holding accessories.*—Several work holding accessories have been developed to prevent slippage of work being machined in a planer. Figure 120 illustrates these accessories while figure 121 shows both correct and incorrect methods of application.

(*a*) The stop pins (fig. 120① and ②) are placed in front of work to prevent its slippage under the pressure of the cut.



① Square head stop pin. ② Round head stop pin. ③ Bunter.

④ Round head screw plug. ⑤ Square head screw plug. ⑥ Toe dogs.

FIGURE 120.—Work holding accessories.

(*b*) The bunter (fig. 120③) and the screw plug (fig. 120④) are used to prevent work from shifting to the side during the cutting operation.

(*c*) The screw plug (fig. 120⑤) is designed for use in holding work against an angle plate.

(*d*) The toe dog (fig. 120⑥) is used in conjunction with screw plugs or thrust blocks for holding thin work to the work table.

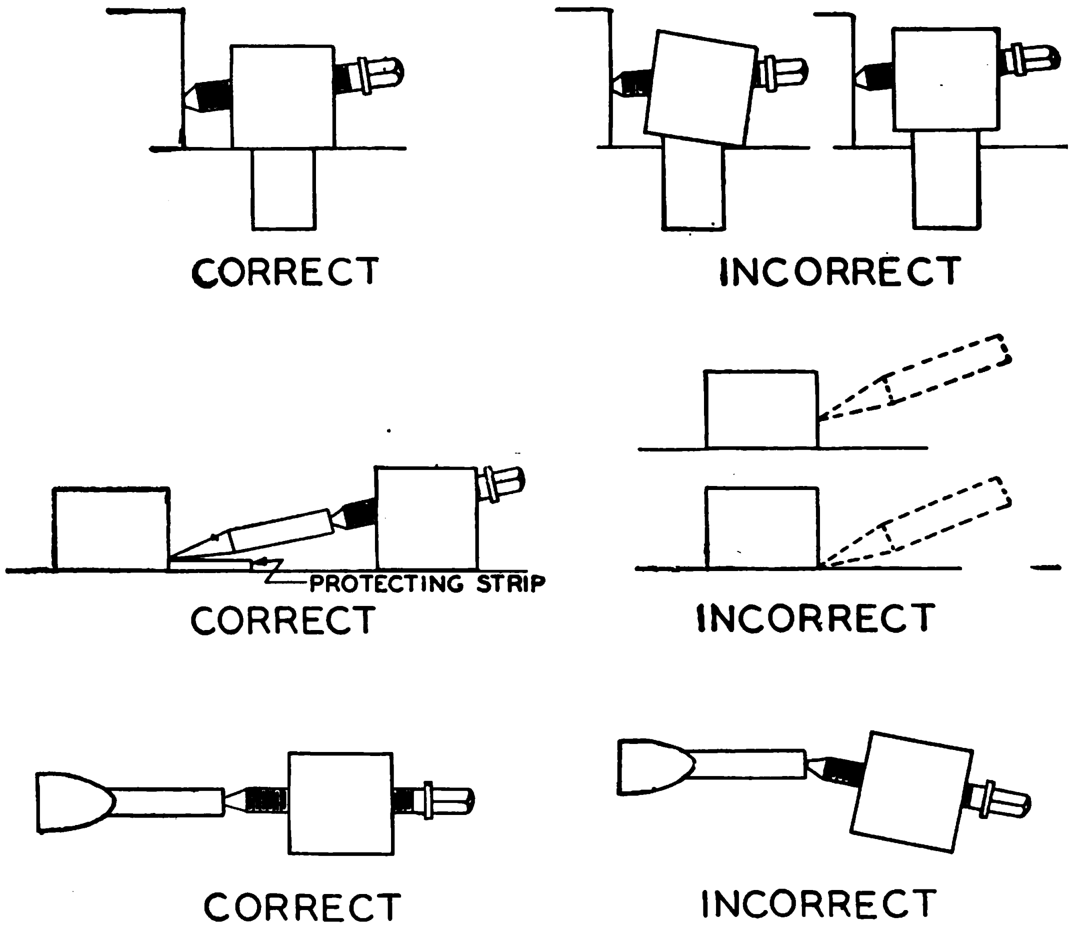


FIGURE 121.—Correct and incorrect applications of work holding accessories.

SECTION VII

SPEEDS, FEEDS, AND CUTTING TOOLS FOR SHAPERS AND PLANERS

45. General.—Shaper and planer tools are similar in shape to lathe tools, differing mainly in the relief angles. Due to the fact that the tool is held practically square with the work and does not feed during the cut, these angles are much less than those required for turning operations. The nomenclature used for shaper and planer tools is the same as that for lathe tools and the elements of the tool, such as the relief and rake angles, are in the same relative positions, as shown in figure 122. Both carbon and high speed steel may be used for tools; however, due to the high production speed possible with modern machines, carbon steel is becoming obsolete.

46. Types of tools.—Several types of tools are required for the various operations that may be accomplished on the shaper or planer. Although, differing considerably as to shape, the same general rules

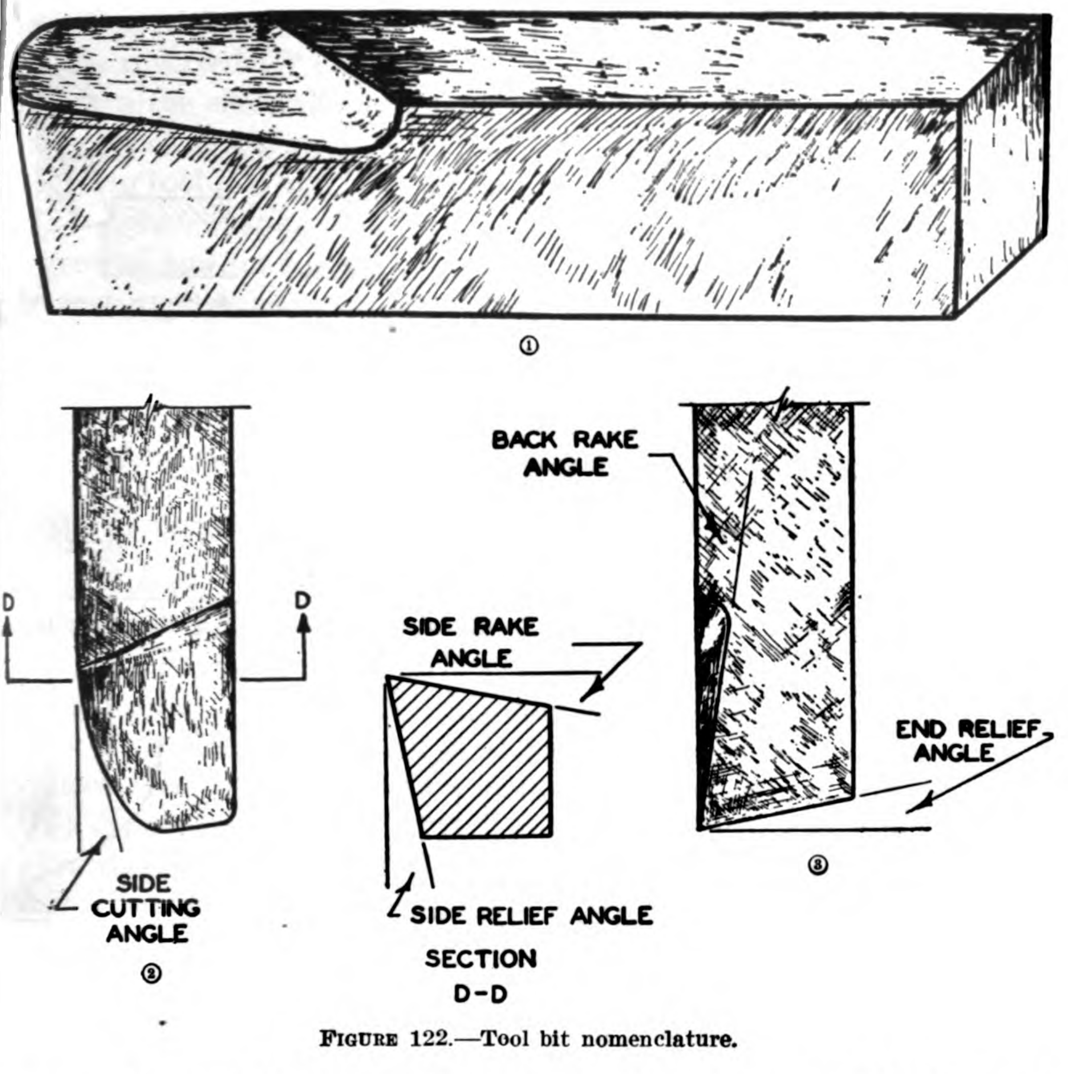
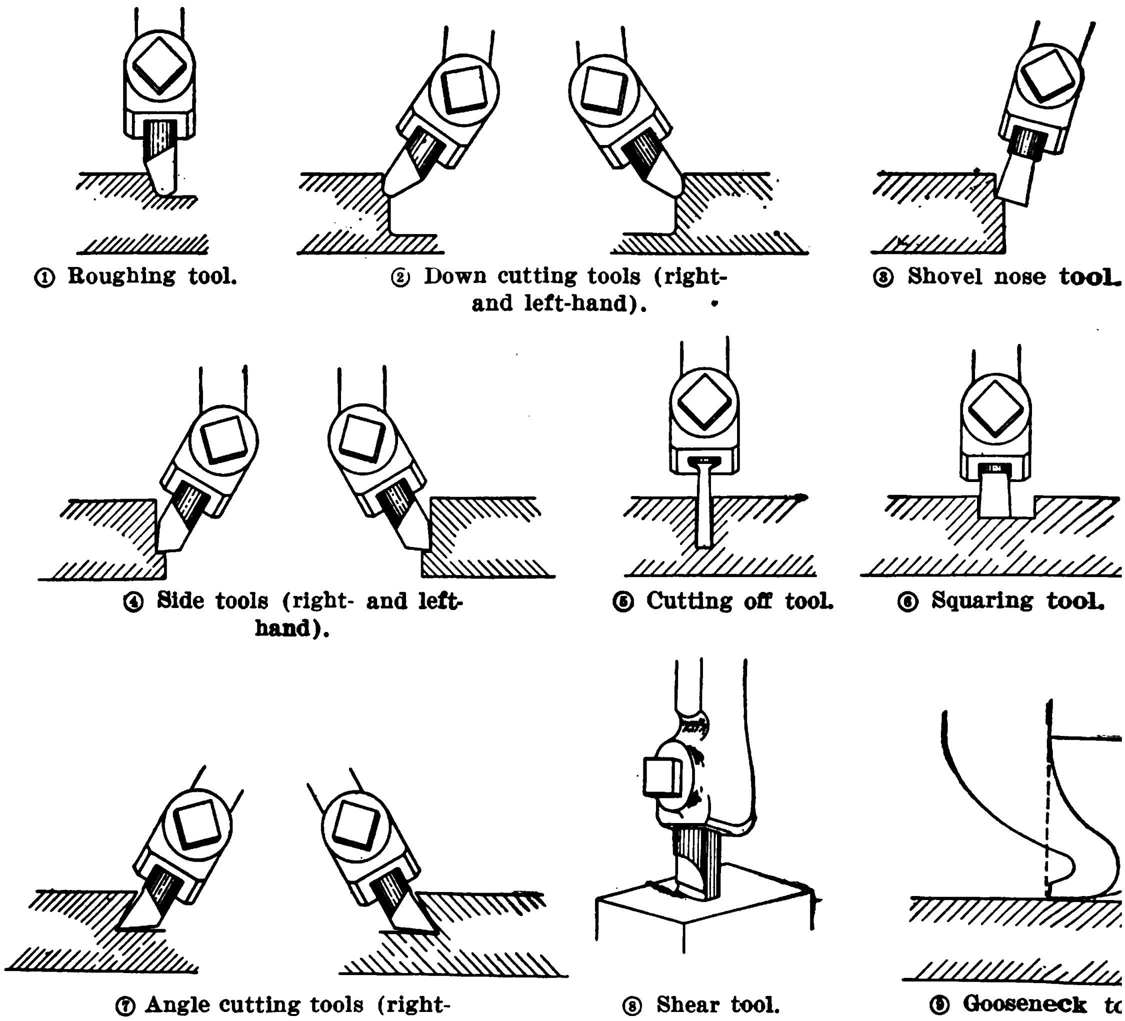


FIGURE 122.—Tool bit nomenclature.

govern the grinding of each type. As in the case of lathe tools, hand forging has been widely used in the past. Tool holders and interchangeable tool bits have, however, largely replaced forged tools as this practice greatly reduces the amount of tool steel required for each tool.

a. In order that it may cut efficiently, the side and end of the tool must be ground so as to give a projecting edge. This is termed side and end relief, and, if insufficient, the tool bit will rub the work causing excessive heat, and producing a rough surface on the work. Should too much relief be given the tool, the cutting edge will be weak and tend to break during the cut. The end and side relief angles, as shown in figure 122, seldom exceed 3° to 5°.

b. In addition to the relief angles, the tool bit must slope away from the cutting edge. This slope is known as a side rake and reduces



① Roughing tool. ② Down cutting tools (right- and left-hand). ③ Shovel nose tool. ④ Side tools (right- and left-hand). ⑤ Cutting off tool. ⑥ Squaring tool. ⑦ Angle cutting tools (right- and left-hand). ⑧ Shear tool. ⑨ Gooseneck tc

FIGURE 123.—Standard shaper and planer tools.

the power required to force the cutting edge into the work. The side rake angle is usually 10° or more, depending upon the type of tool and the metal being machined. Roughing tools are given no back rake although a small amount is generally required for finishing operations.

c. Shaper and planer tools may be ground for either right- or left-hand operation, although the left-hand type is most generally used. The terms right and left hand refer to the direction of cut with respect to the operator; the right-hand tools cutting toward the operator and the left-hand tools away from the operator.

d. The shape and use of the various standard tools are illustrated in figure 123 and may be outlined as follows:

(1) *Roughing tool* (fig. 123①).—This tool is very efficient for general shop use and is designed to take extremely heavy cuts in cast iron or steel. The roughing tool is generally ground for left-hand operation as illustrated; however, for special applications, the angles may be reversed for right-hand cuts. No back rake is given this tool although the side rake may be as much as 20° for soft metals. Finishing operations on small flat pieces may be performed with the roughing tool if a fine feed is used.

(2) *Down cutting tool* (fig. 123②).—The down cutting tool may be ground and set for either right- or left-hand operation and is used for making vertical cuts in a downward direction. The tool is substantially the same as the roughing tool described above with the exception of its position in the tool holder.

(3) *Shovel nose tool* (fig. 123③).—This tool may be used for down cutting in either a right- or left-hand direction. A small amount of back rake is required and the cutting edge is made the widest part of the tool. The corners are slightly rounded to give them longer life.

(4) *Side tool* (fig. 123④).—Both right- and left-hand side tools are required for finishing vertical cuts. These tools may also be used for cutting or finishing small horizontal shoulders after a vertical cut has been made, in order to avoid changing tools.

(5) *Cut-off tool* (fig. 123⑤).—This tool is given relief on both sides to allow free cutting action as the depth of the cut is increased.

(6) *Squaring tools* (fig. 123⑥).—This tool is similar to the cut-off tool and may be made in any desired width. The squaring tool is used chiefly for finishing the bottom and sides of shoulder cuts, keyways, and grooves.

(7) *Angle cutting tool* (fig. 123⑦).—The angle cutting tool is adapted for finishing operations and is generally used following a roughing operation made with the down cutting tool. The tool may be ground for either right- or left-hand operation.

(8) *Sheer tool* (fig. 123⑧).—This tool is used to produce a high finish on steel and should be operated with a fine feed. The cutting edge is ground to form a radius of 3 to 4 inches; twisted to a 20° to 30° angle and given a back rake in the form of a small radius.

(9) *Spring or "gooseneck" tool* (fig. 123⑨).—This tool is used for finishing cast iron and must be forged so that the cutting edge is behind the back side of the tool shank. This feature allows the tool to spring

away from the work slightly, reducing the tendency for gouging or chattering. The cutting edge is rounded at the corners and given a small amount of back rake.

47. Tool holders.—Various types of tool holders, made to hold interchangeable tool bits, are used to a great extent in planer and shaper work. Tool bits are available in different sizes to fit these holders and are furnished hardened and cut to standard lengths. The tool holders most commonly used are described in the following paragraphs:

a. The straight, right-hand, and left-hand holders (fig. 124) may be used for the majority of common planer and shaper operations.

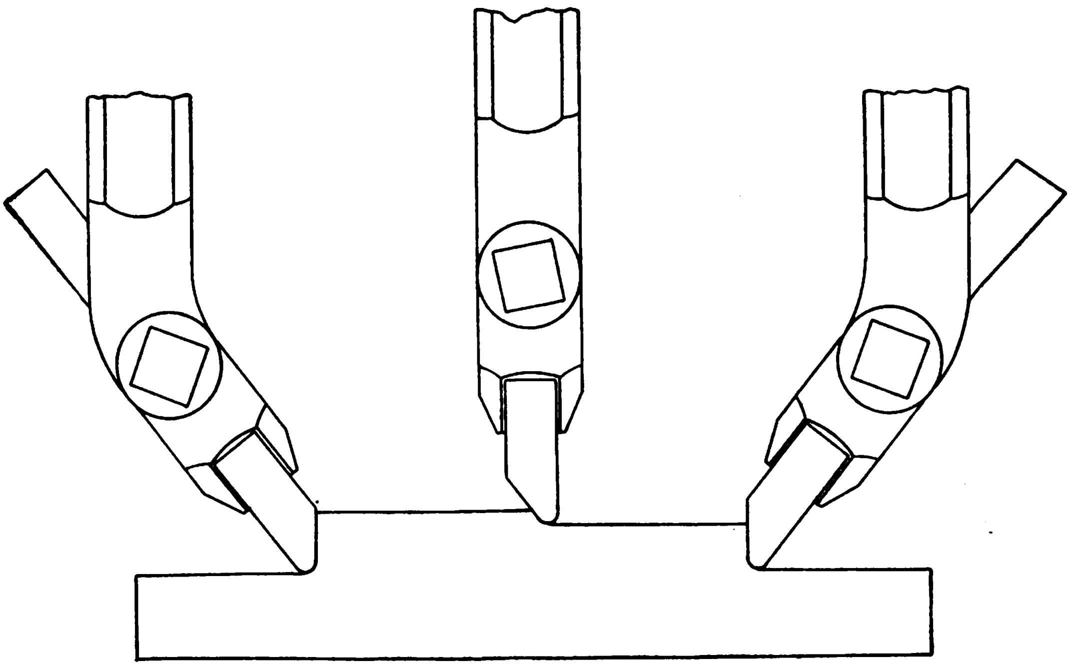


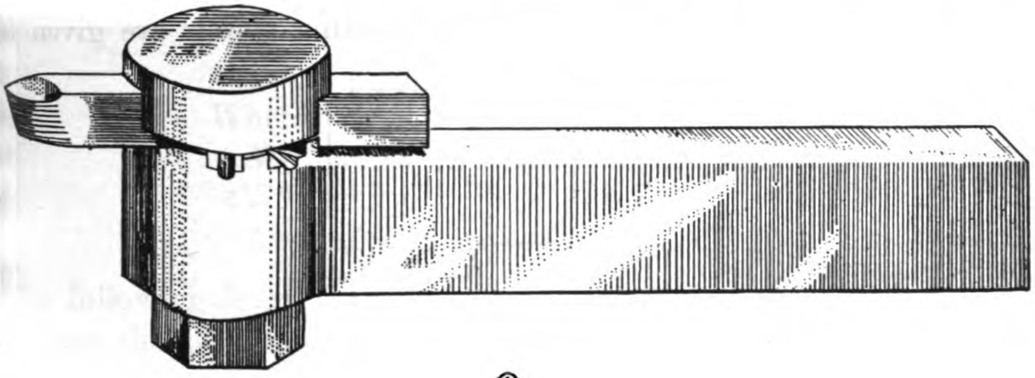
FIGURE 124.—Right-hand, straight, and left-hand tool holders.

b. The swivel head tool holder (fig. 125) is a universal, patented holder that may be adjusted to place the tool in various radial positions. This feature allows it to be converted into a straight, right-hand, or left-hand holder at will.

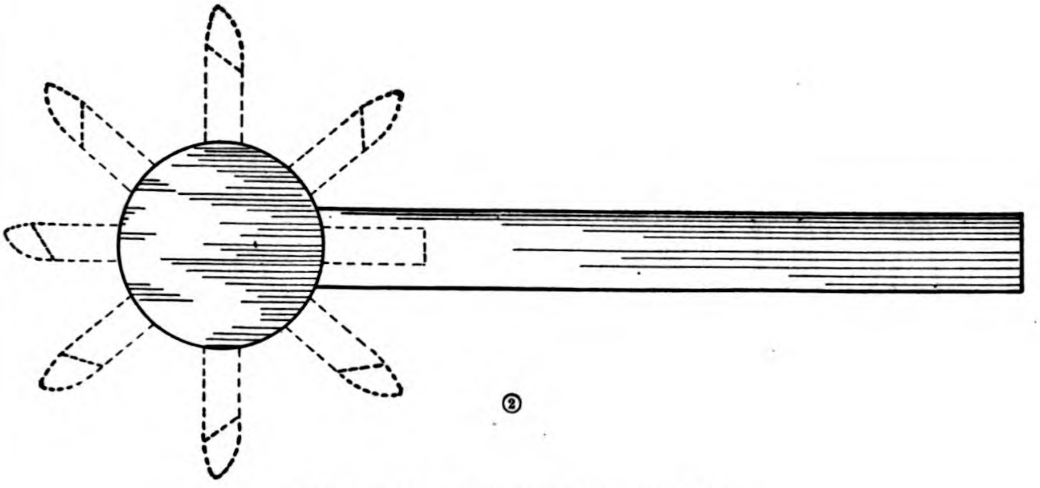
c. The spring tool holder (fig. 126) features a rigid U-shaped spring which makes the holder capable of absorbing a considerable amount of vibration. This holder is particularly valuable for use with formed cutters which have a tendency to chatter and "dig" into the work.

d. The extension tool holder is adapted for cutting internal keyways, splines, etc., on the shaper. As shown in figure 127, the extension arm of the holder may be adjusted both for length and radial position of the tool.

e. The gang tool holder, shown in figure 128①, is only used for production work, where a considerable amount of metal is required



①



②

FIGURE 125.—Swivel head tool holder.

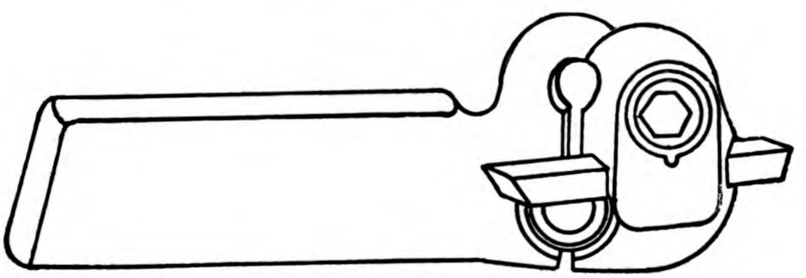


FIGURE 126.—Spring tool holder.

to be removed. As each tool bit is set successively deeper, multiple cuts are made during a single stroke of the machine. Figure 128② illustrates this cutting action.

48. Cutting speeds.—*General.*—The number of strokes per minute required to produce the proper cutting speed depends on the cutting foot speed recommended for metal to be machined and the length of the stroke in inches. Approximate cutting speeds are given for

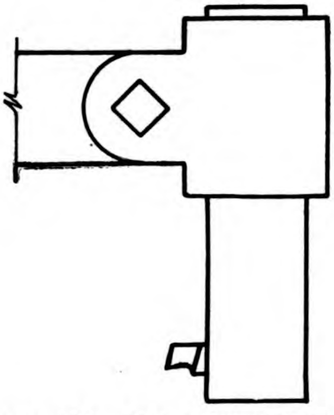
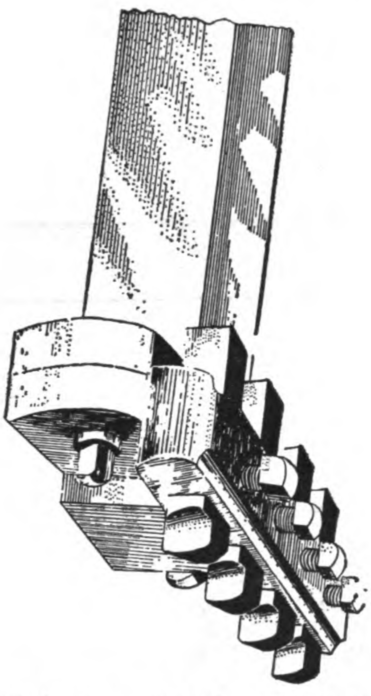
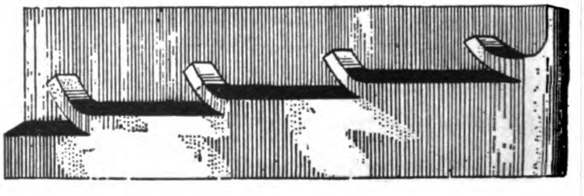


FIGURE 127.—Extension tool holder.



① Arrangement of cutting tools.



② Multiple chip produced by its use.

FIGURE 128.—Gang tool holder.

the more common metals in table XIII. Shapers are adjustable for various numbers of strokes per minute and this setting is independent of the length of stroke. The required strokes per minute may be determined by multiplying the cutting speed by 7 and dividing the product by the length of the stroke in inches. Thus:

$$N=\frac{CS\times 7}{L}$$

Where:
N=number of strokes per minute
CS=cutting speed (table XIII)
L=length of stroke in inches

The following is an example in the use of the formula:

Assume that the number of strokes per minute for rough cutting a piece of tool steel 12 inches long is to be determined.

$$N=\frac{20\times 7}{12}=\frac{140}{12}=11$$

The machine should therefore be adjusted as nearly as possible to give 11 strokes per minute.

TABLE XIII.—*Recommended cutting speeds for various metals*

Material to be machined	Carbon steel tools		High-speed steel tools	
	Cutting speed (feet per minute)			
	Roughing	Finishing	Roughing	Finishing
Cast iron	30	20	60	40
Mild steel	25	40	50	80
Tool steel	20	30	40	60
Brass and bronze	75	100	150	200
Aluminum	75	100	150	200

49. Depth of cut and feed.—The feed and depth of cut of a shaper or planer varies considerably with the type of work being planed and the type of machine employed. Where considerable metal is to be removed, both the feed and depth of cut should be held to a maximum, although in order to avoid overcrowding the machine, it is well to reduce the feed as the depth of cut is increased.

50. Cutting lubricants.—Shaper and planer work does not require the application of a cutting lubricant to any great extent. Its use is, however, recommended during the final operations in the production of fine finishes. The compounds described in the section on milling machines are satisfactory for this purpose.

Section VIII

PLANER AND SHAPER OPERATION

51. Alining the machine.—*a. General.*—Positive alinement must be maintained in both the shaper and planer if the production of accurate work is to be accomplished.

(1) Planers seldom require alinement due to the minimum of adjustable parts involved. Should such a procedure become necessary however, the adjustment must be made on the cross rail. A dial indicator placed between the cross rail and the table will show any variation from the horizontal.

(2) There are several points requiring alinement on the shaper and a check should be made on the accuracy of the machine before attempting any operation requiring extreme precision.

b. Alining the table and tilting table parallel with the ram.—The following is a step-by-step procedure for alining the table and tilting table, the required set-up for which is shown in figure 129.

(1) Remove the vise and thoroughly clean the top surface of the tilting table.

(2) Set the table and tilting table to exact zero by means of their graduated scales.

(3) Clamp a dial test indicator in the tool post, setting the contact point of the indicator approximately $1/16$ inch above the tilting table.

(4) Adjust the stroke of the ram to a length $1/2$ inch less than the length of the tilting table and position the ram so that the contact point of the indicator will not run off the tilting table surface at either end.

(5) Set the machine to operate at its slowest speed.

(6) Start the machine and allow the ram to complete one stroke cycle, stopping it in the middle of the stroke.

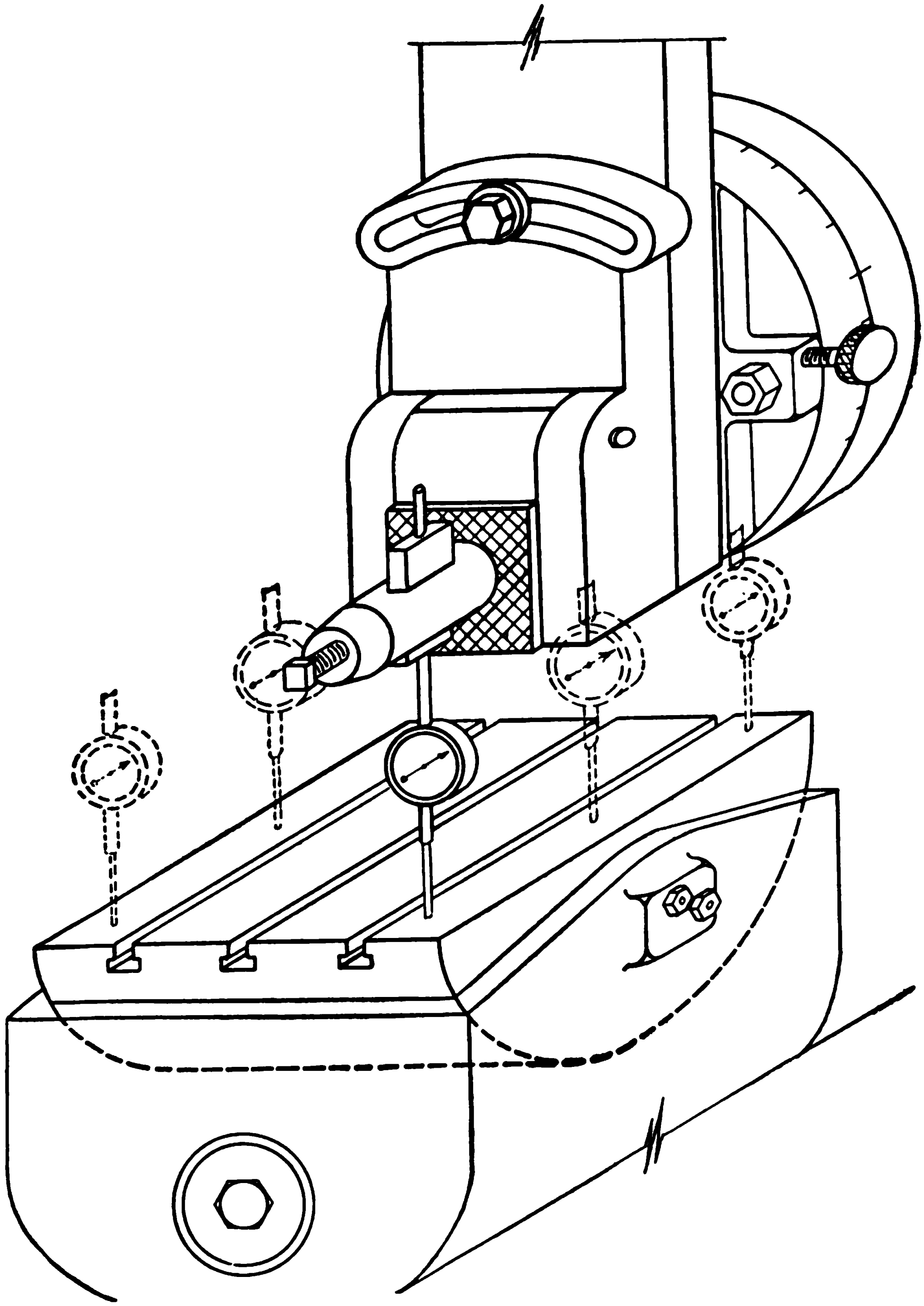


FIGURE 129.—Alining the table and tilting table parallel with the ram.

(7) Adjust the contact point of the indicator so that it bears against the top surface of the tilting table. While adjusting the

indicator, the zero marking on the indicator face should be set a the top of the dial to facilitate reading the instrument.

(8) Using the cross feed ratchet lever, move the table to brin the indicator to the opposite side of the tilting table.

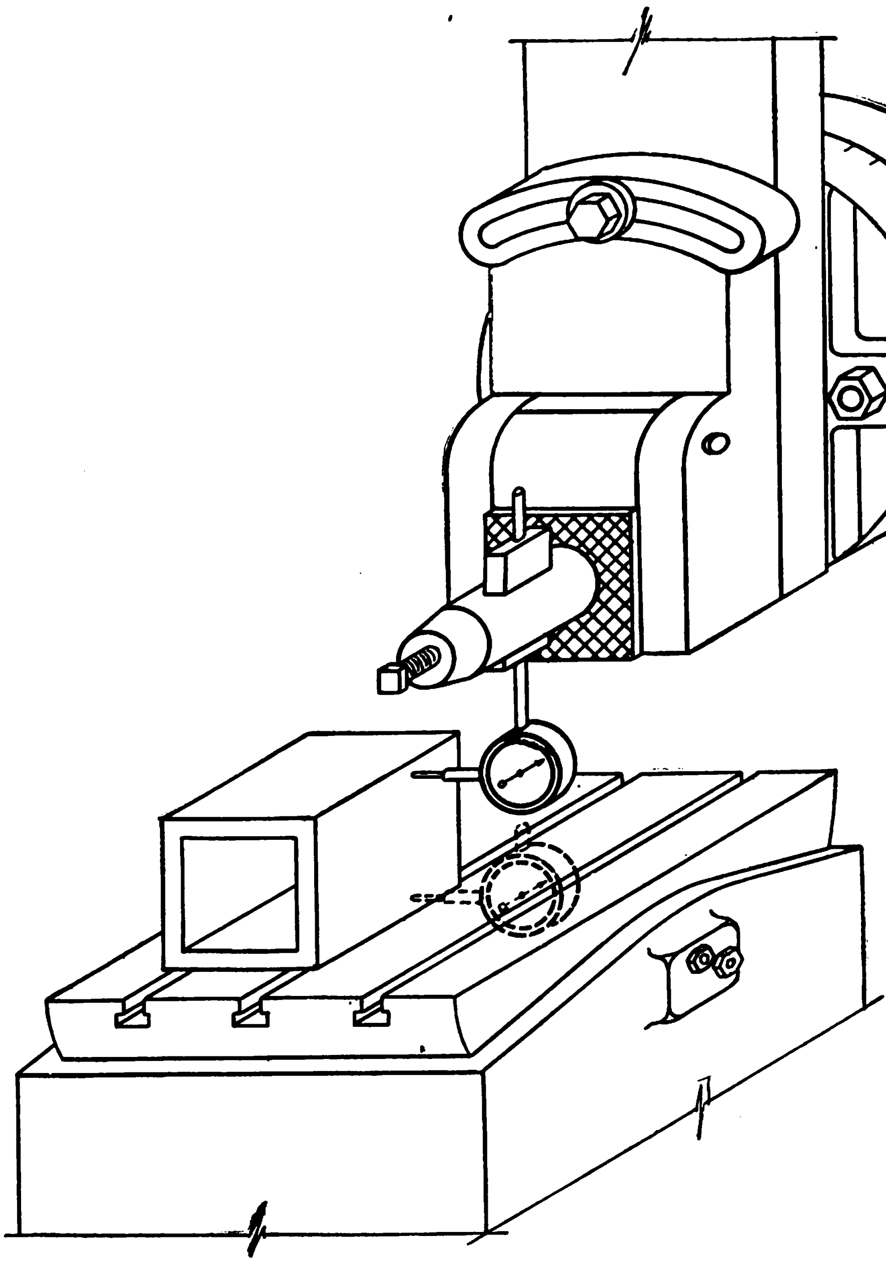


FIGURE 130.—Setting the tool slide square with the table top.

(9) Should the indicator show misalinement, make the necessar adjustment on the table to bring the indicator back to its zer reading.

(10) Move the ram until the indicator contacts the front end o the tilting table and, if the indicator hand has moved, reset it to zero

Continue to move the ram until the indicator contacts the rear end of the tilting table and if any variation is indicated, adjust the tilting table.

(11) Take final readings at the four corners of the tilting table, as indicated in figure 129, and make any further adjustment necessary to complete the alinement.

c. Setting the tool slide square with the table top.—This adjustment is only necessary when vertical down cuts are to be taken. The following is the procedure required for making the alinement, the set-up for which is shown in figure 130.

(1) Place a box type parallel on the table so that its sides are parallel to the sides of the table.

(2) Clamp a dial indicator in the tool post and adjust the tool slide so that the contact point of the indicator is in line with the parallel.

(3) By means of the cross feed ratchet lever, bring the contact point of the indicator to bear against the parallel and set the dial to indicate zero.

(4) Using the tool slide feed screw handle, lower the tool slide to its maximum down feed position and note the reading of the indicator as the slide is lowered.

(5) If the reading at the lowest point is equal to that at the highest point, the tool slide is square with the table and no adjustment is required. However, should a variation exist between the readings, it may be corrected by loosening the two bolts that bind the swivel to the ram, and making the required adjustment. Should it be desired to make this alinement without removing the vise, the parallel may be placed on the bottom surface of the vise and the above procedure followed.

d. Alining the vise jaws parallel with the ram.—This alinement is required before making cuts that are to be parallel to the vise jaws. The set-up required is illustrated in figure 131, and the necessary procedure is outlined as follows:

(1) Unlock the vise on its swivel base and set the reference line on the vise, to the zero line of the graduated base, clamping it lightly in this position.

(2) Install a dial test indicator in the tool post, as shown in figure 131.

(3) Set the stroke of the ram to a length ½ inch less than the length of the vise jaw and position it so that the indicator contact point will not run off the vise jaw at either end.

(4) Bring the stationary vise jaw against the contact point of

the indicator, then move the ram until the point of contact is at the rear of the jaw.

(5) Set the dial to zero and move the ram so that the point of the indicator contacts the front of the vise jaw.

(6) Should the indicator hand remain at the zero position, no adjustment is necessary; however, when a variation is indicated,

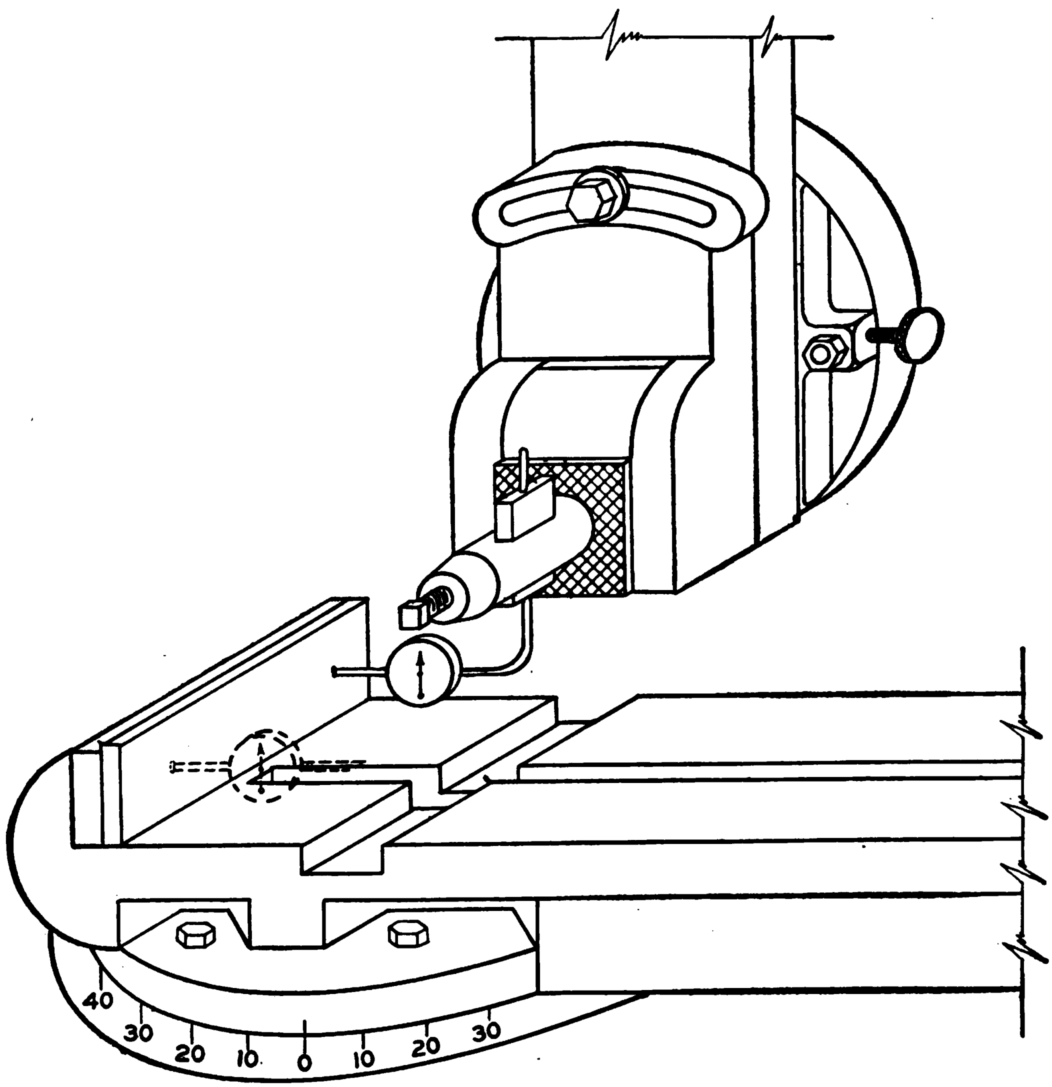


FIGURE 131.—Alining the vise jaws parallel with the ram.

alinement may be made by bumping the vise in the required direction with the heel of the hand.

(7) Tighten the bolts, locking the vise to its base and recheck the reading of the indicator at both ends of the jaw.

e. Alining the vise jaws square with the ram.—This alinement is required for all accurate operations where planing is to be done with the pressure of the cut against the vise jaws. The set-up is illustrated in figure 132, and the procedure may be outlined as follows:

(1) Unlock the vise from its swivel base and swing it until the reference mark coincides with the 90° graduation on the base. Lightly clamp the vise in this position.

(2) Mount the dial indicator in the tool post and open the vise sufficiently to allow the contact point of the indicator to bear against the stationary jaw.

(3) Position the ram so that the contact point of the indicator clears the jaw by 1/16 inch.

(4) By means of the tool slide feed screw handle, adjust the tool slide to bring the indicator contact point into position near the face of the vise jaw.

(5) By means of the ram positioning shaft, bring the contact point of the indicator to bear against the vise jaw, as illustrated in figure 132.

(6) Position the indicator to one side of the jaw by turning the cross feed ratchet lever.

(7) Using the cross feed lever, move the vise until the point of the indicator contacts the opposite side of the vise jaw and note the indicator reading.

(8) When a variation is shown, adjust the vise an amount equal to 1/2 the error.

(9) Recheck the setting at each end of the vise jaw and, when the jaw is in alinement, lock the vise to the swivel base.

(10) Make a final check after the vise has been locked in position, completing the operation.

52. Adjusting the length of stroke.—*a. General.*—The length of the shaper or planer stroke should be adjusted to accommodate each new work set-up where a change in the working dimensions is involved. When too long a stroke is employed, a considerable amount of time is wasted during the stroke cycle, whereas too short a stroke will, of course, fail to completely machine the surface.

b. An adjustment of the planer stroke consists simply of shifting the trip dogs attached to the side of the machine. This may be done by loosening the clamp nuts and sliding the dogs to the required positions.

c. The method of adjusting the length of the shaper stroke depends upon the type of shaper being used.

(1) On the older type shapers, the stroke is adjusted as follows:

(*a*) Move the ram to the extreme rear of its travel and loosen the stroke adjusting nut.

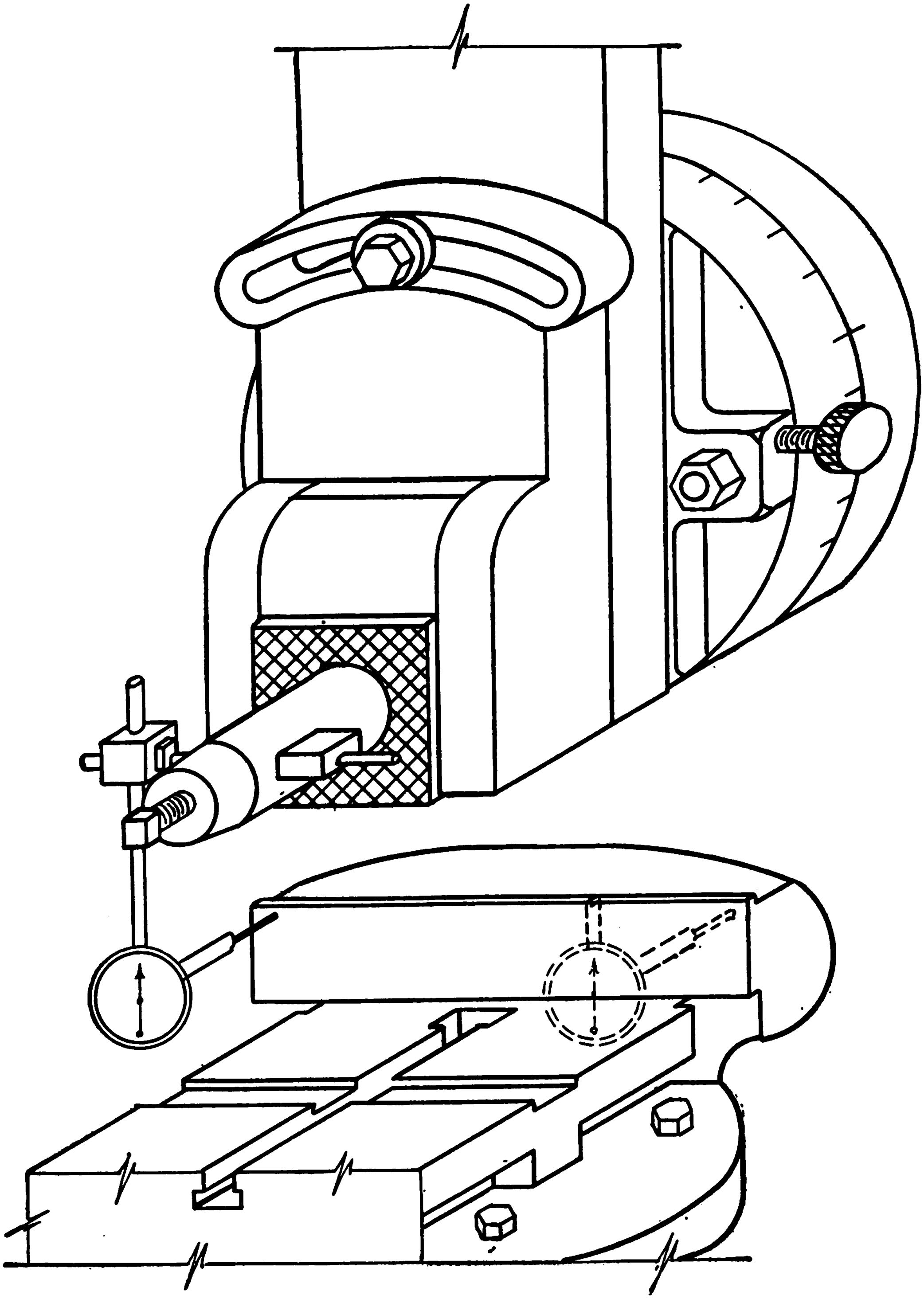


FIGURE 132.—Alining the vise jaws square with the ram.

(b) Place the cross feed lever on the stroke adjusting shaft, and turn the shaft until the scale mounted on the column indicates the desired length of stroke.

(c) Lock the stroke adjusting nut, completing the adjustment.

(*d*) Never attempt to adjust the length of stroke while the ram is in motion.

(2) The more modern types of shapers, such as shown in figure 111, are equipped with direct reading indicators for speeds, feeds, and lengths of stroke. In this case, the length of stroke is set by turning the adjusting shaft or screw until the desired setting has been obtained, as indicated by a reading on the dial. This dial is placed alongside the stroke adjusting shaft and is graduated to read in inches of ram travel. The stroke, for shapers equipped in this manner, may be adjusted while the ram is in any position.

d. In either of the above types of machines the stroke should usually be set to travel one inch in excess of the length of work. This overtravel is to allow the tool to clear the work at each end.

53. Positioning the stroke.—In the case of the planer, the adjustment for stroke length also definitely positions the stroke and no additional setting is required. The shaper stroke must, however, be positioned as a separate operation. In making this adjustment, the one inch of overtravel referred to in the preceding paragraph is generally divided so that the tool clears the work $7/8$ inch at the rear of the stroke and $1/8$ inch at the front. The following procedure is given for positioning the stroke and the adjustment should only be made while the ram is at rest:

a. Move the ram to the extreme back of its stroke and loosen the ram clamp 25, figure 111.

b. Place the positioning lever on the ram positioning shaft and turn until the tool is in position $7/8$ inch to the rear of the work.

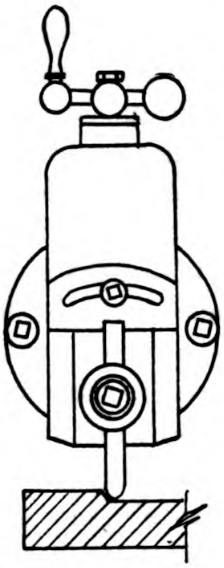
c. Tighten the clamp and check the amount of overtravel at the front of the work, completing the adjustment.

54. Setting the clapper box.—*a. General.*—The clapper box assembly is composed of a box, block, and hinge. The rectangular box is open at each end and on top and is attached to the tool slide by means of a stud or screw pivot which allows a swivel adjustment in either direction. The block (clapper block) is closely fitted into the box and hinged at the top with a pin. The tool post extends through a hole in this block to receive the cutting tool.

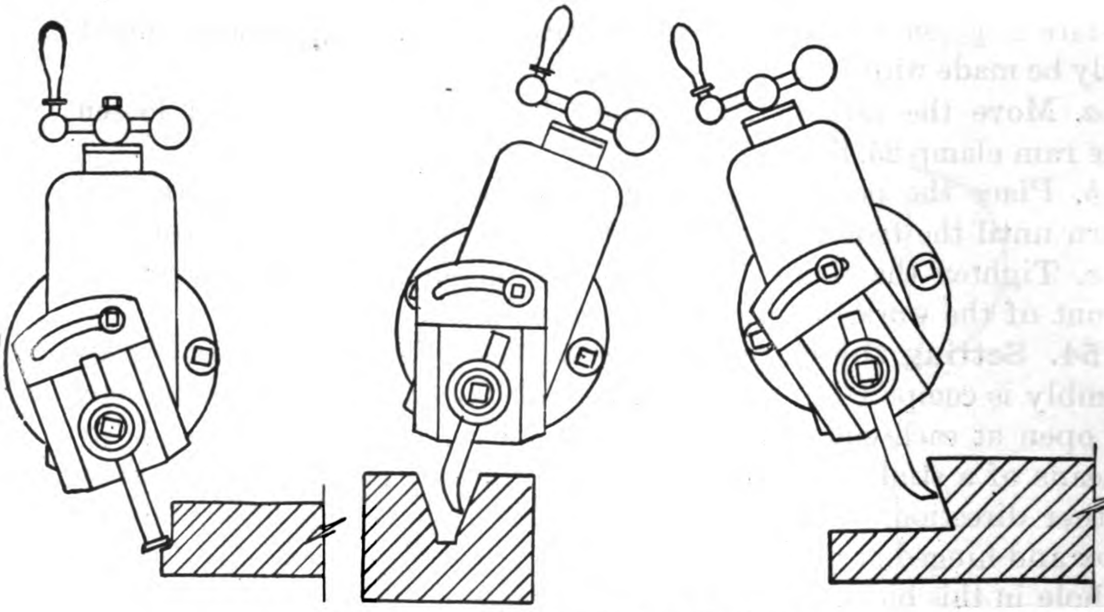
b. When taking side or down feed cuts, the top of the clapper box is swiveled away from the surface being cut. This setting is illustrated in figure 133②, ③, and ④ and permits the block to hinge forward on the return stroke, allowing the tool to clear the surface being cut.

c. Horizontal cuts are taken with the clapper box in the vertical position, as shown in figure 133①.

55. Holding work.—*a. General.*—In machining operations on the shaper and planer, the proper securing of the work is of utmost importance. Due to the variety of jobs that may be done on these



① Position for horizontal cutting.



②, ③, and ④ Positions for down cutting.

FIGURE 133.—Positioning the clapper box for various operations.

machines, many different problems are presented and care must be exercised in the selection of the proper set-up for each case. The springing of work, during the clamping operation, must be avoided if accuracy is to be obtained. In heavy parts, where only a relatively small amount of metal is to be removed, the danger of springing is slight; however, in light or irregularly shaped work, it is a factor that must be carefully considered. The springing of work may be due to two causes, each of which is explained as follows:

(1) *Springing due to excessive clamping pressure or faulty application of the clamping device.*—This trouble may be overcome by the use of care and good judgment while making the set-up.

(2) *Springing due to the relief of internal strains when the outer surface of the metal is removed.*—This trouble may be minimized by roughing all external surfaces before any finishing cuts are taken. When the shape of the work is such that its thickness is many times less than its length and width, the work should be left on a level table for a considerable period of time between the roughing and finishing operations.

b. Work holding procedure for the shaper or planer is very similar to that employed in milling machine practice. Due to the reciprocating motion of the cut, stop pins, special clamps, etc., are used as an added precaution against slippage.

56. Planing parallel and square surfaces.—*a.* In this and following operations, the term "planing" refers to machining operations on either the planer or the shaper. The production of parallel and square surfaces is a fundamental planing operation and may best be described by means of the following procedure outline for squaring the sides and ends of a block:

(1) Aline the vise jaw parallel with the direction of the stroke.

(2) Set the block in the vise and plane one of its largest surfaces, as shown in figure 134①.

(3) Loosen the vise and place the surface just planed against the stationary vise jaw, as shown in the figure 134②. After making sure that the block is well seated, plane the upper surface. More positive seating of the finished surface against the stationary vise jaw may be obtained by inserting a rod or strip between the movable vise jaw and the work, as shown in the figure.

(4) Place the surface just planed on parallels or against the bottom of the vise so that the first surface planed is against the stationary vise jaw as shown in figure 134③. Tap the block solidly in place with a hammer made of soft material and plane the upper surface. As in the preceding step, a strip or rod may be used between the work and the movable vise jaw to assure positive seating.

(5) Place the first surface planed on parallels or against the bottom of the vise, as shown in figure 134④ and after clamping and seating the work, plane the remaining side.

(6) Square the ends of the block by either of the following methods:

(*a*) Short pieces should be set on end, either on the bottom of the vise or on suitable parallels, and one of the finished sides set perpendicular, by using a square, as shown in figure 135. When making this setting the work should be clamped lightly and tapped into alinement with a soft hammer. A final check should be made after the vise is tightened and the upper end finished by taking horizontal cuts. The piece may then be reversed in the vise and the opposite end planed, after the work is firmly seated by tapping with a soft hammer.

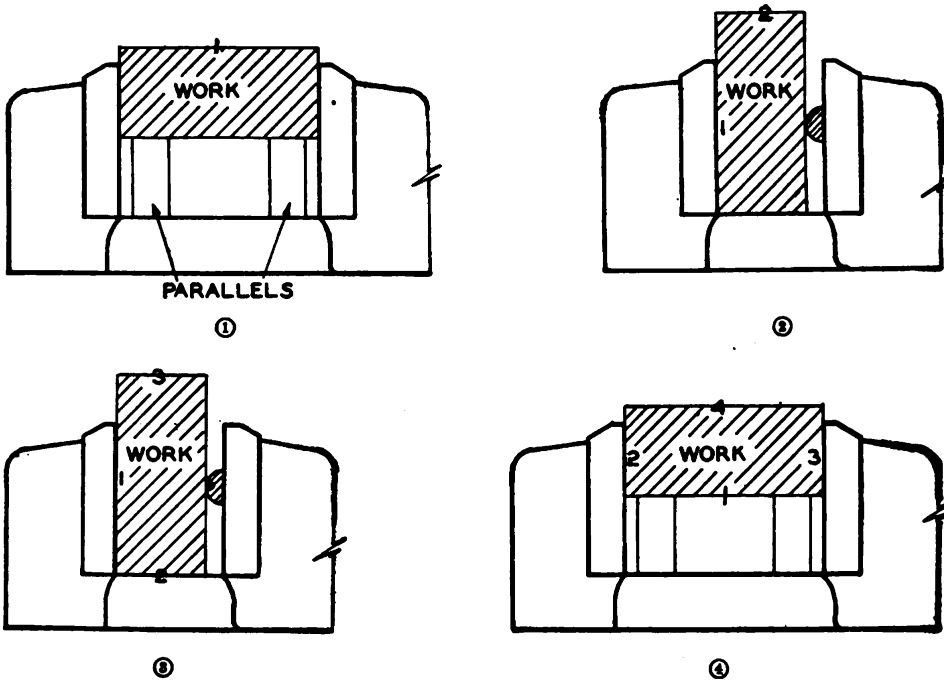


FIGURE 134.—Squaring a block.

(*b*) Long pieces should be set lengthwise in the vise with one end extending beyond the vise jaws. After seating, the end is squared with down feed cuts.

1. During this operation the work may be placed on parallels or set against the bottom of the vise.

2. While making the down feed cuts, it is essential that the top of the clapper box be swiveled away from the surface being cut, to give the tool clearance on the return stroke, as shown in figure 133.

3. The feed and depth of cut should be less than that used for horizontal planing as the tool is extended some distance away from the tool post, reducing its rigidity.

b. Other methods that may be used for planing right angular surfaces are described as follows:

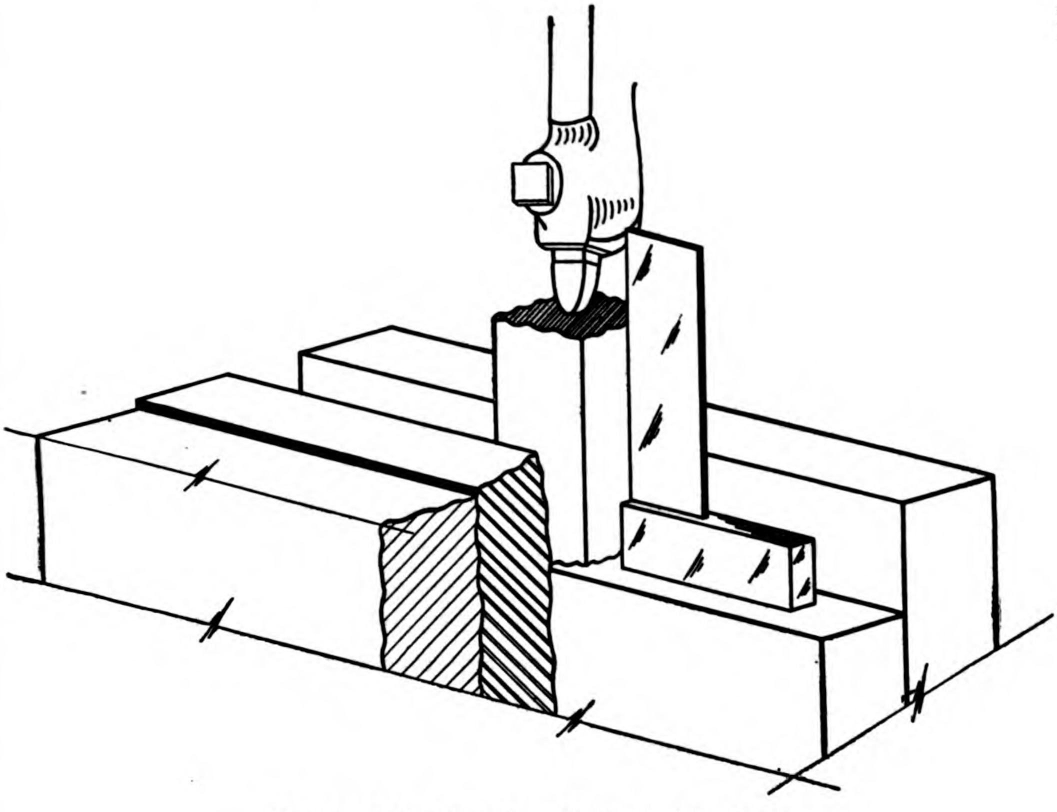


FIGURE 135.—Squaring the ends of a block.

(1) The work may be clamped directly to an angle plate mounted on the shaper or planer table. In this case, the face of the angle plate takes the place of the stationary vise jaw. After one surface

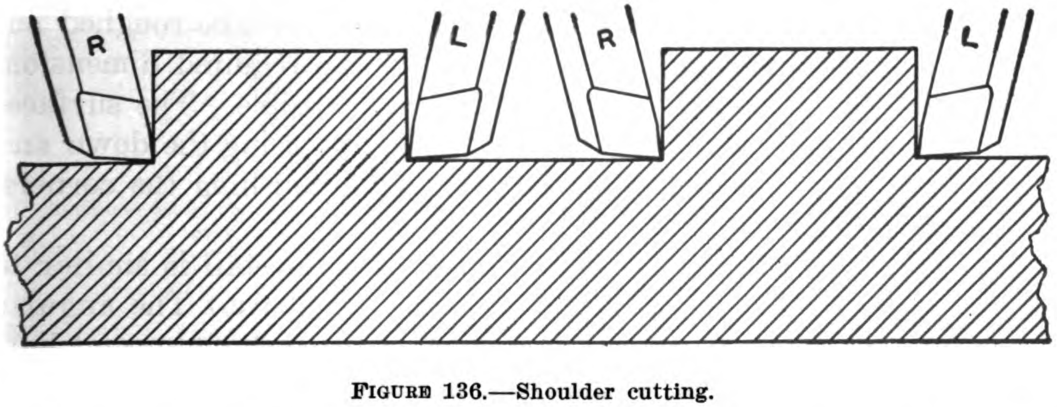


FIGURE 136.—Shoulder cutting.

of the work has been planed, this surface is clamped to the angle plate and the operation repeated on the opposite side.

(2) The work may be clamped to the side of the work table. When this method is employed, the side of the table is used as the reference instead of the vise jaw or angle plate.

(3) The work may be clamped directly to the top surface of the table, so that it extends beyond the table side. In this case, the exposed surface is finished by down feed cutting.

c. When only two opposite sides are to be planed parallel, the work is clamped in the vise and one side finished by horizontal planing. This finished surface is then placed down on the table, the bottom of the vise, or on suitable parallels and held in place by means of hold-down straps, toe dogs, or poppets, while the remaining side is machined. Figures 54, 58, and 121 illustrate typical set-ups for performing this operation.

57. Parting.—The cutting off or parting operation requires that the work be rigidly clamped in position as considerable resistance is offered by most metals during the process. It is also necessary that extreme care be used in grinding and setting the cutting tool. A suitable cutting lubricant is recommended when parting steel or wrought iron. In the clamping of work in the vise, the surface to be parted should be held as close to the vise jaws as possible, to provide additional support. The cutting speed used must be considerably less than that required for other planing operations, and the overrun of the tool should be increased, to allow a greater clearance at the rear of the stroke. The cut is made to progress by down feeding with the tool slide, and as the depth of the cut increases, the amount of feed should be reduced. During the parting operation, the clapper block must be raised by hand on the return stroke, to prevent the tool from binding in the cut.

58. Shoulder planing.—When planing to a shoulder, as in the cutting of tongues and grooves, the work should first be roughed out to within a few thousandths of an inch of the required dimension, using the regular round nose tool whenever possible. The surfaces of the tongue or groove may then be finished by using the down and cross feeds. Special tools must be ground for finishing the corners, as shown in figure 136.

59. Dovetail planing.—The planing of a dovetail is similar to the cutting of a tongue or groove as described above. The angular surfaces of the dovetail are cut by down feeding with right- and left-hand angle cutting tools, as shown in figure 137.

a. When cutting angular surfaces, the swivel head is set to the complement of the angle to be cut. This complementary angle is determined by subtracting the required angle from 90°. Thus: Complementary angle = 90° − angle to be cut.

When the swivel head is set over for an angular cut, care must be

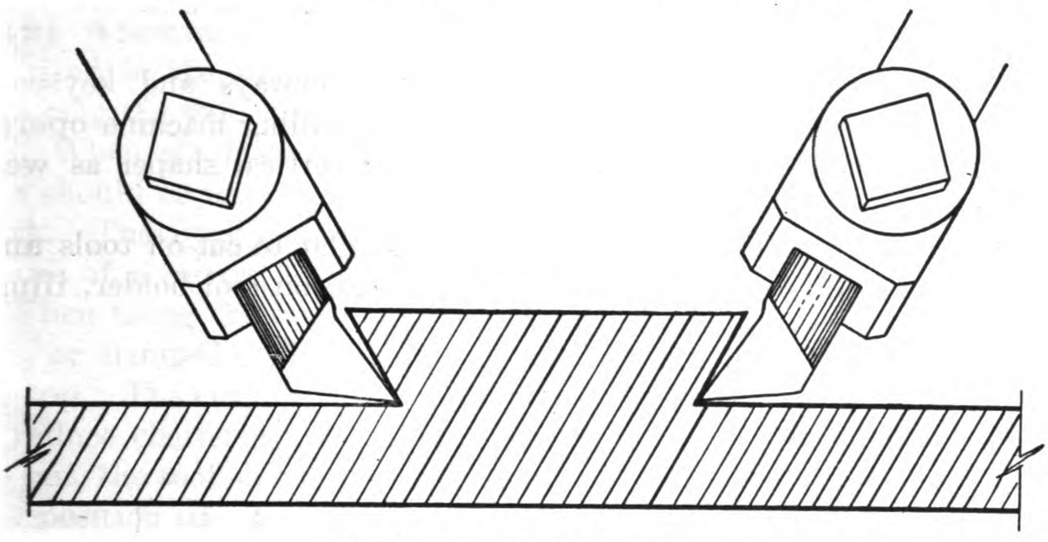
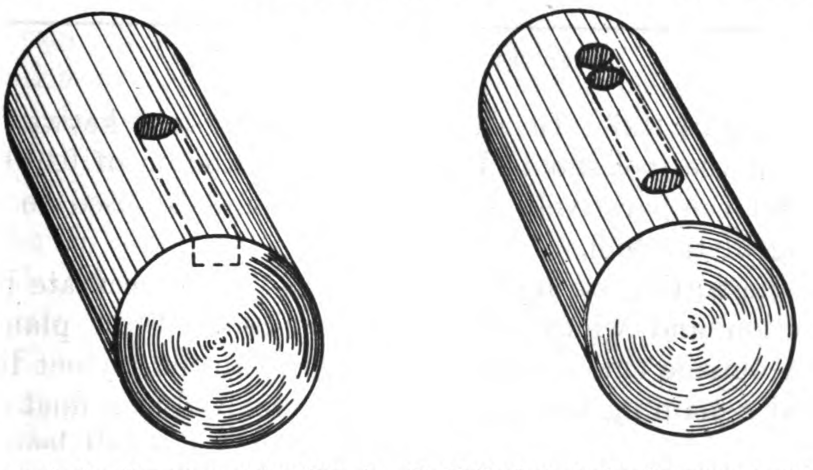


FIGURE 137.—Dovetail planing.

used to see that the tool slide will not strike the column as the ram moves to its starting position.

b. Before making the set-up, the outline of the dovetail should be laid out on a finished surface of the work and prick punched to pro-



① Method used for keyways extending to end of shaft. ② Method used for keyways terminating in shaft.

FIGURE 138.—Starting holes for keyway planing.

vide a better outline. The work may then be clamped in the machine and roughed out with a roughing tool. Finishing should be accomplished with right- and left-hand angle cutting tools such as illustrated in figure 123⑦. During the planing process the work should not be disturbed until all the surfaces have been machined.

c. The method of measuring dovetails is described under dovetail milling in section IV. Whenever possible, the mating member of the dovetail being cut should be used to test its accuracy, however, a test gage cut from sheet metal may be used as a satisfactory substitute.

60. Keyseat and keyway planing.—Keyways and keyseats which have been described in the section on milling machine operation, may also be cut on the horizontal and vertical shaper as well as the planer.

a. The tools used for this operation are similar to cut-off tools and internal keyways require the use of the extension tool holder, illus-

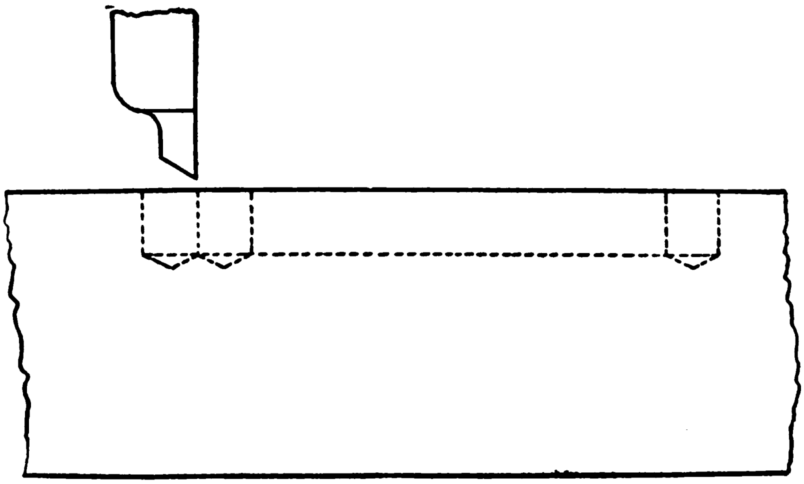


FIGURE 139.—Key slotting tool.

trated in figure 127. In all cases of keyseat and keyway planing, the feed of the tool should be held to a maximum of 0.010 inch per stroke and comparatively slow speeds should be used to eliminate springing of the tool.

b. In the cutting of keyseats and keyways, an accurate lay-out of the position and width of slot is required. When planing wide keyseats, outside cuts should first be made to the lay-out lines, then the metal remaining between these cuts removed as a final operation.

c. When planing keyways that do not run the full length of the shaft, a hole must be drilled at the point where the cut will terminate. As shown in figure 138①, this hole must be of the same width and depth as the keyway. This practice prevents the building up of chips in front of the cutting tool and allows the keyway to be made to full size throughout its length.

(1) Where both ends of the slot must terminate in the metal of the shaft, holes must be drilled as shown in figure 138②. Two adjacent holes are usually made at the starting point and the metal chipped out

between them to allow the tool to drop into position at the beginning of each stroke.

The cutting tool required for the above planing operation should be ground, as illustrated in figure 139, to eliminate interference.

(2) Wherever cuts must terminate in the metal, extreme accuracy is required in the adjusting and positioning of the stroke to prevent breaking the tool.

d. When planing internal keyways in gears, pulleys, etc., a radial line should be inscribed on the hub to assist in the alinement of the work. The work may then be set into position on the machine, by means of a square, using the inscribed line as a reference.

When using the horizontal shaper, the work may be held in the vise, or clamped to the table or angle plate so that the keyway is at the top. The cut may then be made by feeding upward which tends to reduce chattering and binding of the tool bit. Before starting the cut, the tool should be raised until it just touches the work. In this position the graduated dial on the tool slide is locked and used as a guide in determining the correct depth of cut.

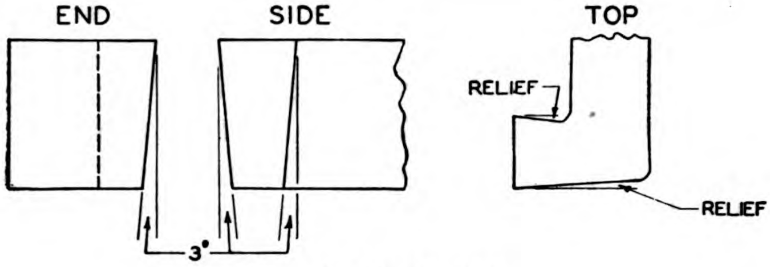
61. T-slot planing.—Although most small T-slots are cut on the milling machine, the shaper or planer is generally used for those of large dimension.

a. After the required outline has been inscribed, the work is set up in the machine and a groove is planed to the desired depth with a squaring tool. This groove should be slightly narrower than the required width of the T-slot neck. The undercuts of the T-slot may then be planed, using right- and left-hand T-slot tools, as illustrated in figure 140. The neck of the T-slot is finished to the required width by down cutting as a final operation.

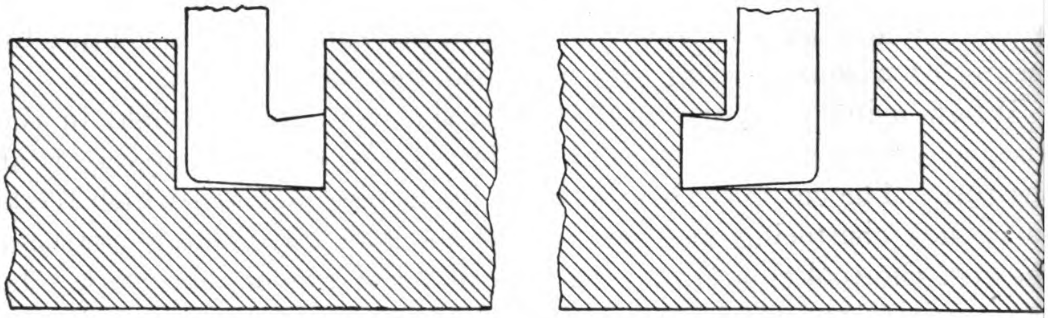
b. In order to eliminate its dragging in the slot, the tool must be given end and side relief. In addition, the cutting edge is made the widest part of the tool and the top surface is ground flat. When planing a T-slot it is necessary either to block the tool so that it cannot lift, or to lift the tool to clear the work on the return stroke. This precaution prevents the tendency for the tool to lift against the shoulder, marring the surface, and dulling or breaking the cutting edge.

(1) When the tool is to be lifted out of the slot on the return stroke, a tool lifter may be used to eliminate lifting the tool by hand. A simple tool lifter, such as shown in figure 141, can be quickly made from a strap hinge.

(2) To block the tool, the tool block or clapper may be locked in the clapper box by means of a screw or by using a piece of ma-

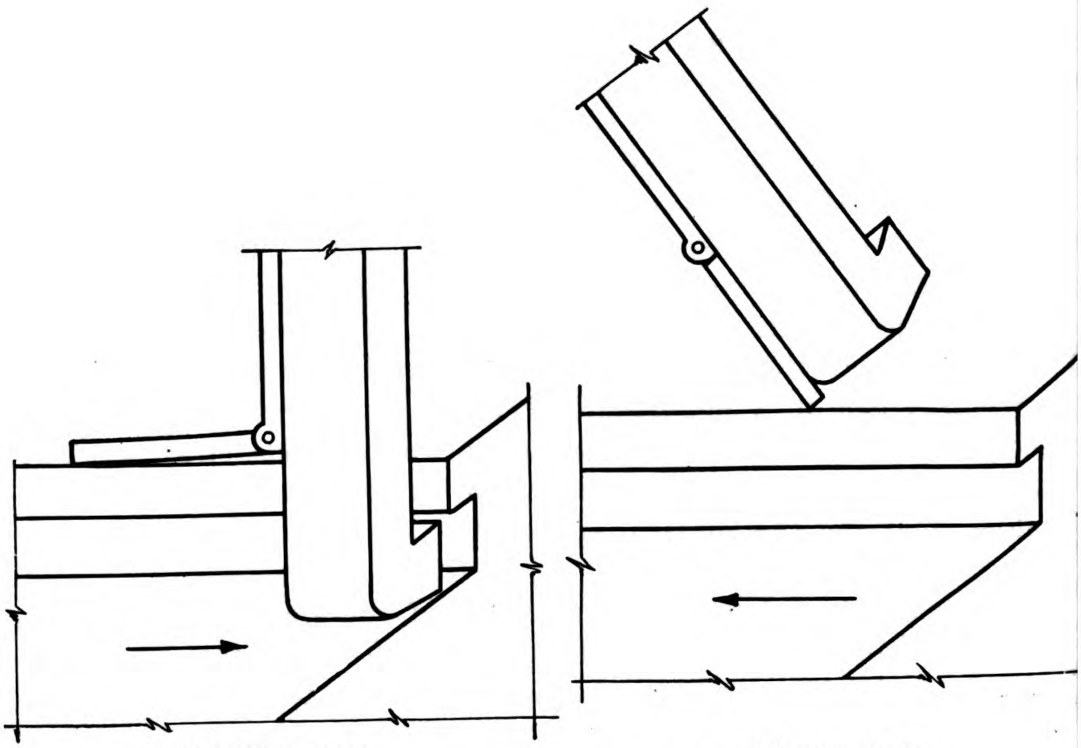


① T-slot planing tool.



② Starting the undercut. ③ Undercutting.

FIGURE 140.—T-slot planing.



① Cutting stroke. ② Return stroke.

FIGURE 141.—Application of tool lifter.

terial placed between the back of the tool and the tool slide, as illustrated in figure 142.

c. Undercuts which are similar to T-slots may be cut, using the method outlined above. In this case, the tool can usually be of a larger size, allowing heavier cuts to be taken.

62. Taper planing.—*a.* Taper planing is the machining of non-parallel surfaces and is employed in the production of taper keys, gibs, wedges, and other work of a similar nature. Several methods

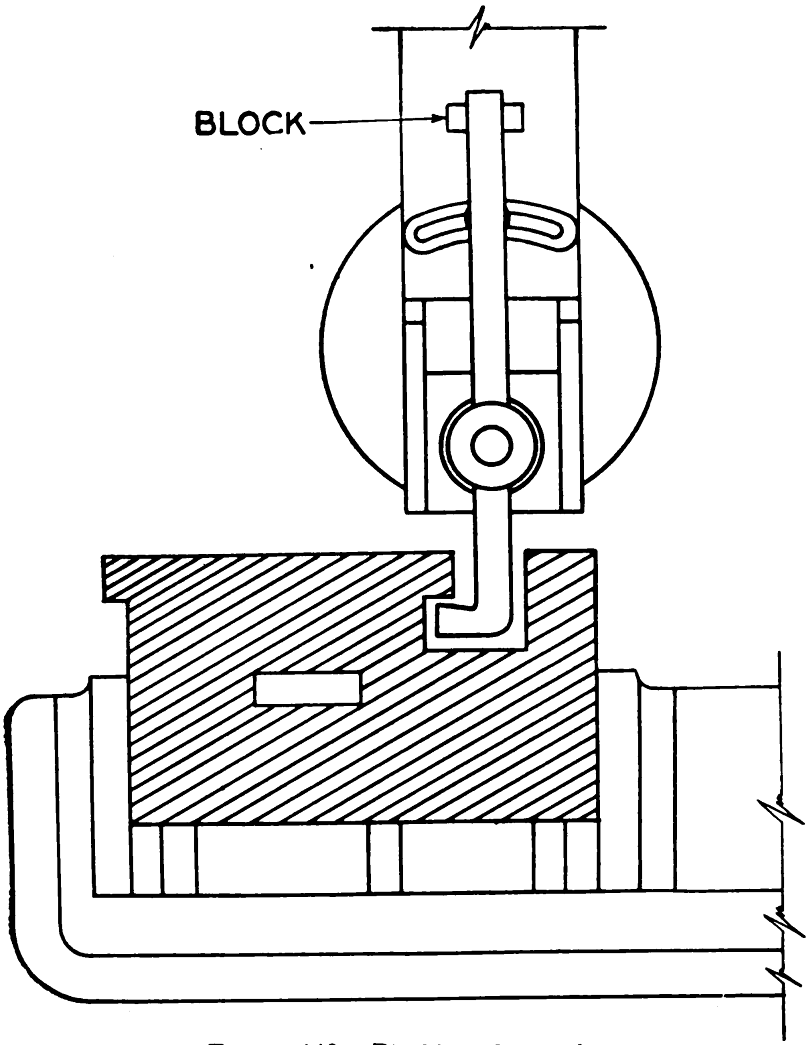


FIGURE 142.—Blocking clapper box.

may be used for holding work for this operation, the use of each being governed by the shape and size of the piece, as well as the number of pieces to be machined. In general practice, the work is held in the vise or clamped to an angle plate in such a position that the inclined surface to be planed is parallel to the table top.

b. When several pieces are to be machined to the same taper, the tilting table or table may be adjusted to the required angle. In this case, the pieces being machined may be mounted flat against th inclined surface of the tilting table or table, or held in a vice mounte on this surface. The tilting table and table adjustments are gradu ated in degrees and it will, therefore, be necessary to convert th taper specified for the work to an angular measurement when thi method is to be used. The tangent of the required angle may b found by determining the taper per inch. This tangent converte into degrees determines the tilting table or table setting. To conver

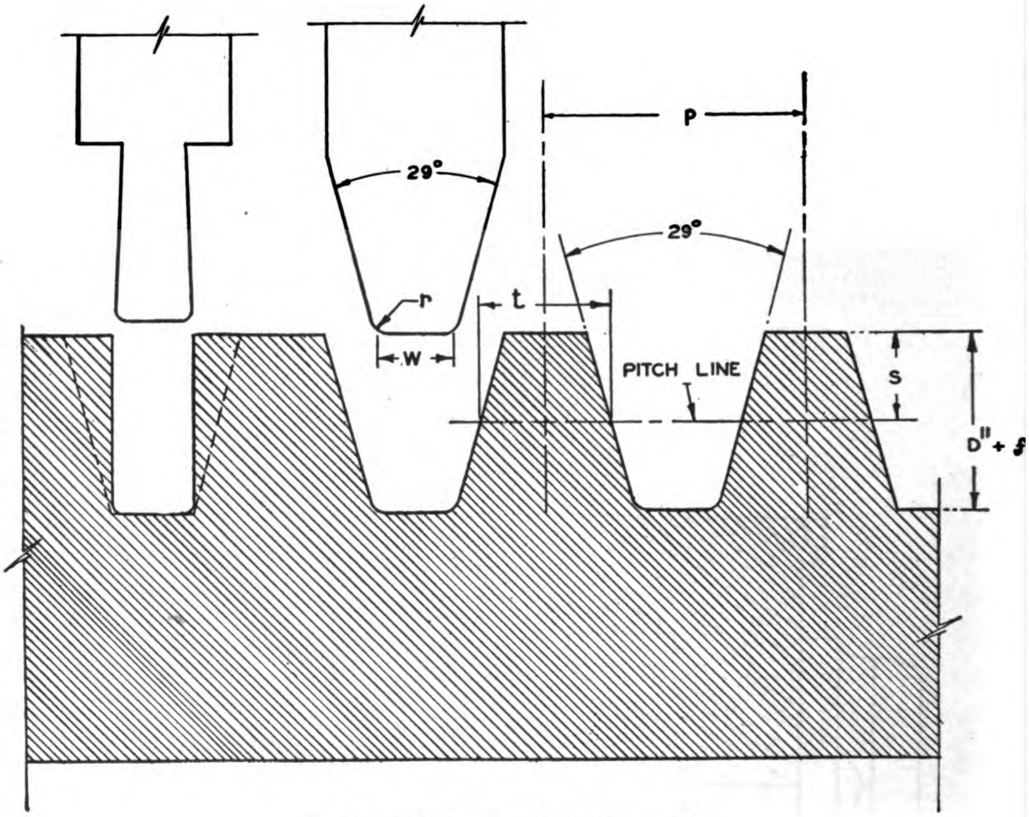


FIGURE 143.—Rack cutting tool.

the taper per inch to degrees, the angle may be taken directly fro a trigonometric table of tangents.

c. As an example of the above calculation, assume that it is require to set the tilting table for a taper of ¾ inch per foot; therefor ¾ ÷ 12 = 0.0625 (the taper per inch). The angle whose tangent 0.0625 = 3°34′44″. The tilting table may then be set to the require angle by the use of the graduations provided for this purpose. Th accuracy of the setting may be determined by using a dial test ind cator mounted in the tool holder.

63. Rack planing.—*a.* The cutting of rack teeth is generall done by milling as discussed in section V. However, the shaper or planer may be used for this purpose when necessary.

b. The shape of the rack cutting tool should be the same as that of the rack tooth, which in turn, is the same as that of a gear tooth of like pitch, as shown in figure 143. The following are standard proportions for a rack cutting tool:

(1) The included angle between the sides of the tooth for involute gears having a 14½° pressure angle is 29°.

(2) The whole depth of a full depth tooth ($D''+f$) equals the linear pitch (P') multiplied by 0.6866.

(3) The tooth width at the pitch line (t) equals one-half the linear pitch (P').

(4) Before the corners are rounded on the end of the rack tool, its width (w) should equal the linear pitch (P') multiplied by 0.31.

(5) The radii (r) on the corners of the tool equal 0.066 multiplied by the pitch.

(6) When measuring the width of the rack tooth with a vernier tooth caliper, the distance from the top of the tooth to the pitch line (s) equals the linear pitch multiplied by 0.3183.

c. (1) When planning rack teeth, each tooth space is indexed a distance equal to the linear pitch (P'). This spacing or indexing may be accomplished by means of the micrometer dial on the cross feed screw. To determine the amount of cross feed movement corresponding to each mark on the dial, manufacturer's charts may be consulted or direct readings taken with a micrometer or dial indicator. The tool should be moved continuously in one direction when making an adjustment, in order to avoid errors, due to lost motion between the screw and feed nut.

(2) During the planing operation the work may be held in the vise or clamped directly to the work table. After the work has been mounted and positioned, the tooth space is generally roughed out in the form of a plain, rectangular groove with a roughing tool, then finished with a tool ground to the size specified above.

d. The sequence of operations required in the planing of a rack may be outlined as follows:

(1) Clamp the work in the vise or to the table.

(2) Position a squaring tool which is smaller in width than the required tooth space, so that the tool is centered with the first tooth space to be cut.

(3) Set the graduated dial on the cross feed screw to zero, and use it as a guide for the spacing of the teeth.

(4) Move the tool slide down until the tool just touches the work and lock the graduated collar on the tool slide feed screw.

(5) Feed the tool slide down slightly less than the whole depth of the tooth, using the graduated collar as a guide and rough out the first tooth space. Start the machine and feed the tool slide down slightly less than the whole depth.

(6) Raise the tool to clear the work and move the cross feed a distance equal to the linear pitch of the rack tooth by turning the cross feed lever. Rough out the second tooth space and repeat this operation until all spaces are roughed out.

(7) Replace the roughing tool with a tool ground to size, for the tooth form desired, and aline the tool with a bevel protractor.

(8) Adjust the work so that the tool is in proper alinement with the first tooth space that has been rough cut.

(9) Set the graduated dial on the cross feed screw at zero and use it as a guide for spacing the teeth.

(10) Move the tool slide down until the tool just touches the work and lock the graduated collar on the tool slide feed screw.

(11) Feed the tool slide down the whole depth of the tooth, using the graduated collar as a guide, and finish the first tooth space.

(12) Raise the tool to clear the work and move the cross feed a distance equal to the linear pitch of the rack tooth by turning the cross feed lever.

(13) Finish the second tooth space, then measure the thickness of the tooth with the vernier gear tooth caliper. The tool slide should be adjusted to compensate for any variation indicated by this measurement.

(14) Repeat the process of indexing and cutting until all teeth have been finished.

64. Planing irregular surfaces.—Irregular surfaces commonly planed are convex and concave radii. Forming tools are efficient for finishing narrow irregular surfaces, while wider surfaces are usually planed by cutting to an inscribed line. When planing to an inscribed line, as illustrated in figure 144, it is good practice to rough to within 1/16 inch of the line, then with a file, bevel the edge to the line. Such a procedure eliminates tearing of the line by the breaking of the chip. The vertical hand feed, in conjunction with the power table feed, may be used when planing a wide curved outline.

65. Internal planing.—This process may be used in the production of flat or irregular internal surfaces such as cutting the teeth, in an internal gear, or the points of a box wrench. Internal planing is best accomplished on the vertical shaper, however, when such a

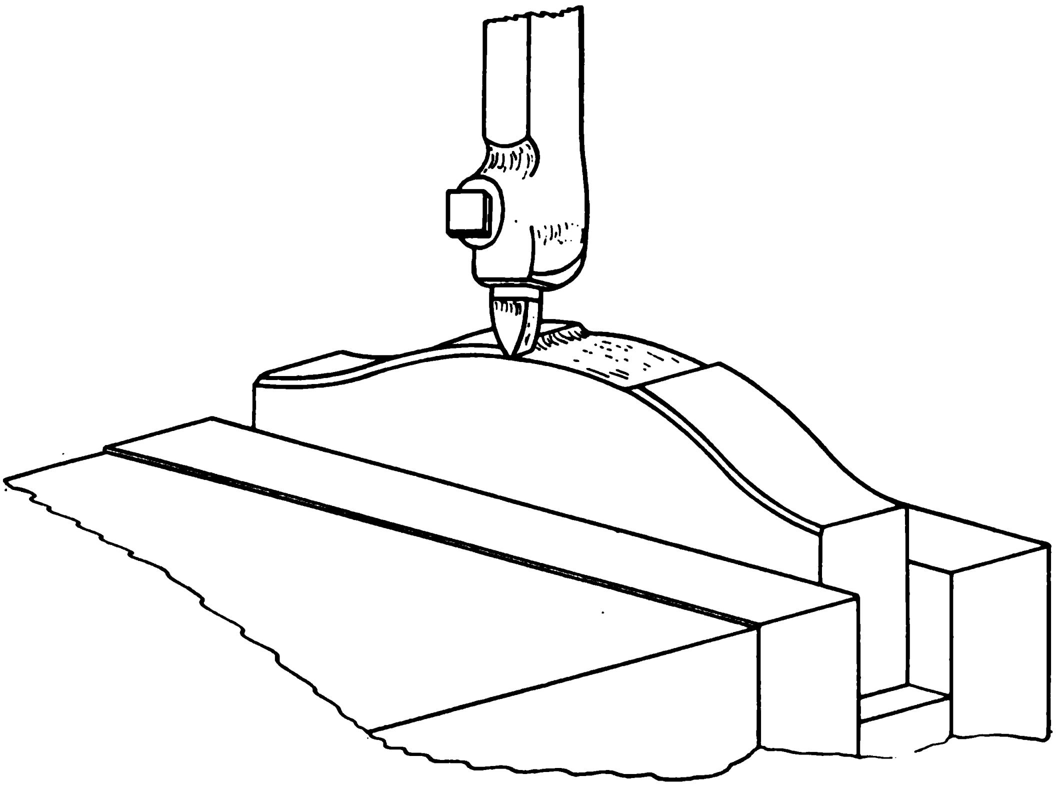


FIGURE 144.—Planing an irregular surface.

machine is not available, the conventional horizontal shaper or planer may be employed, using the extension tool holder. In any case, the work is generally held in a vise or clamped directly to the table top.

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[A. G. 062.11 (1-22-42).]

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